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TREATMENT TECHNOLOGIES

FOR

LANDFILL LEACHATES

A Literature Review

(December, 1994)

Prepared by:

Science and Technology Branch
Ontario Ministry of Environment and Energy

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TREATMENT TECHNOLOGIES FOR LANDFILL LEACHATES

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1.0 INTRODUCTION

1.1 Purpose

During recent years, there has been an increasing concern about the environmental impact and pollution problems caused by leachates generated from municipal solid waste (MSW) landfills. There have been intensified efforts to develop a better understanding of leachate generation as well as methods for leachate management.

The purpose of this report is to provide state-of-the-art information related to the management of leachates from municipal landfill sites. The information presented summarizes various technologies for the control and handling of leachate problems. It is drawn from the published literature, MOEE (Ontario Ministry of Environment and Energy) funded research projects and practical experiences. Guidance on provincial requirements and good waste management practices are included in the "Guidance Manual for landfill sites receiving municipal waste"[93]. **This document is not, and should not be used as design guidelines endorsed by the Ministry.** Mention and/or review of various technologies in this literature review does not mean that the technologies are acceptable to the MOEE.

Since there are no two municipal landfill sites alike in terms of their hydrogeologic conditions, locations, and environmental impacts, leachate must be dealt with on a case-by-case basis. Fine tuning the treatment facility at a particular landfill will require laboratory and field testing. Landfill leachate is different from most other liquid wastes in that its chemical composition and volume vary with time. This variation complicates the design of treatment systems.

1.2 Legislation and Approval

For the purposes of treatment, landfill leachate may be considered "sewage" under the Ontario Water Resources Act (OWRA).[1] Also "sewage works" would include the collection, transmission, treatment and disposal of landfill leachate.

Some of the treatment technologies presented in this document are innovative, experimental or unproven in Ontario. The landfill owner/operator can consider any of these technologies. However, the onus is on the landfill owner/operator to prove the acceptability of a particular technology in the approval process. As a result, proponents of landfills must obtain approval for leachate handling and treatment systems from the Director of the Approvals Branch under Section 53 of the OWRA. For those works not subject to OWRA, approval under Part V of the Environmental Protection Act (EPA) must be obtained.[2]

Duplicate applications for approval are to be sent to the Director of the Approvals Branch and to the local district office of the Ministry of Environment and Energy. Reviews of the application by Ministry staff will be arranged and co-ordinated by staff of the Approvals Branch. Guidelines for obtaining approval are available from that Branch.

A technical review of all parts of the leachate system is made to confirm that applicant's claims regarding performance and effluent quality are reasonable and that Ministry and environmental impact requirements will be met.

2.0 LEACHATE QUALITY

2.1 Generation

Leachate is a liquid which has percolated through landfilled wastes and has extracted dissolved and/or suspended materials from the wastes. The liquid may come from:

a) infiltration of rainfall or snow melt;
b) inflow of ground water;
c) water generated as a product of decomposition;
d) liquid originally in the waste.

Whenever water comes into direct contact with the landfilled wastes, it will become contaminated as many materials in landfills are readily soluble. Other materials become more soluble through the biological and chemical degradation of the wastes within the landfill.

Theoretically, any time the volume of water entering a landfill exceeds the field capacity of the deposited refuse, leachate will be produced and discharged to the environment. The generation and volume of leachate is therefore usually variable and follows a pattern similar to that of the precipitation in the area. The major portion of the leachate will be produced during those months when a significant amount of rainfall has percolated through the soil into the landfilled refuse (assuming that the refuse moisture content has reached its field capacity).[3][4]

The leachate, or contaminants in the leachate, will migrate at different rate into the ground water, depending on the quality of the liners or confining layers beneath the landfilled material. Under some circumstances, such as poor cover material and/or slope selection, leachate can break out as springs, create runoffs and contaminate surface waters. Leachate can be collected from the bottom of landfills by using engineered drainage systems.[5]

Stegmann and Ehrig[6] estimated the mean flow rates of leachate from landfills in West Germany to be in the range of 10 to 25 percent of the precipitation. In North America, an average landfill of 6.88 ha in size with an annual infiltration rate of 25.4 cm can generate an estimated 17,410 m^3 of leachate per year.[7]

2.2 General Leachate Characteristics[4][5][7]

Leachate characteristics vary widely with time and from place to place in the same landfill. No reliable method has been developed to forecast the exact composition of leachate from a particular landfill at a particular time. A borehole leachate sampling program can only provide an approximation of the quality of the leachate. A more critical measurement is the monitoring of the quality of the leachate discharged from the leachate collection system.

Leachate varies widely in composition because of:

a) refuse characteristics;
b) hydrogeology of the site;
c) climate;
d) season;
e) age of the site;
f) depth of refuse;
g) moisture content;
h) leachate flow rate;
i) rate and characteristics of infiltrating water;
j) sampling and analytical techniques (affecting leachate results).

Physical, chemical and biological factors in a landfill influence decomposition rate, leachate generation and leachate characteristics. These factors include:

a) biological decay of putrescible organic materials under aerobic or anaerobic conditions, which produce different types of by-products;

b) chemical reactions of organic and inorganic substances which are dependant on leachate acidity, type of wastes landfilled and landfill temperature;

c) solubility of organic and inorganic substances contained in refuse;

d) movement of dissolved material by concentration gradients and osmotic factors.

Table 1 lists the anticipated trends of the amounts of the various leachate components in a landfill over time.

Table 2 summarizes the various changes taking place in the leachate composition as the wastes buried in the landfill undergo progressive stages of decomposition in an anaerobic environment [8][90]. These changes are described in detail in Sections 4.6.2. Anaerobic Biological Treatment.

The colour of the leachate can vary from green to brown, depending on the chemical quality of the rainfall and the age of the landfill. If the leachate is fresh, its colour can be dark green and becomes dark brown upon exposure to the atmosphere. This is caused by chemical oxidation of ferrous iron compounds in the leachate to ferric compounds. The leachate may be clear to opaque depending on its content of suspended particles.

The odours emitted by the leachate can vary from slight to a strong chemical or barnyard smell.

Leachate samples collected directly from the base of a landfill are generally significant in the following constituents:

a) iron (ferric and ferrous);
b) organic nitrogen;
c) hardness;
d) biochemical oxygen demand (BOD_5);
e) chemical oxygen demand (COD);
f) phosphate;
g) sulphate;
h) total solids (dissolved/suspended);
i) toxic organic compounds.

Leachate quality and quantity will be site specific.

2.3 Organic Carbon Compounds[9]

Organic carbon compounds can be found in high concentrations in landfill leachate because of the generally high organic nature of all refuse. Analyses of the leachate for organic content includes the determination of:

a) total organic carbon (TOC);
b) biochemical oxygen demand (BOD_5);
c) chemical oxygen demand (COD);
d) volatile fatty acids (VFA).

Table 1: Anticipated Change of Leachate Components With Time

	Parameter	Predicted Trend
A.	Components that will degrade or properties that will change:	
	Alkalinity	Decrease
	Biochemical Oxygen Demand (BOD_5)	Decrease - Organics to CO_2, CH_4
	Chemical Oxygen Demand (COD)	Decrease - Organics to CO_2, CH_4
	Nitrate Nitrogen (NO_3-N)	Decrease - to NH_3
	Total Kjeldahl (TKN)	Decrease - to NH_3
	pH	Increase - toward neutrality
	Total Dissolved Solids (TDS)	Decrease
	Specific Conductivity	Decrease
	Sulphate (SO_4)	Decrease
	Volatile Acids (VA)	Decrease
	Total NO_3-N	Increase
B.	Immobilized Compounds	
	Iron (Fe)	Decrease
	Lead (Pb)	Decrease - function of pH increase
	Zinc (Zn)	Decrease
C.	Compounds with enhanced or unaffected mobility	
	Chloride (C1)	Very little change

Source: Report to Congress:
Waste Disposal Practices and Their Effects on Ground Water
Executive Summary, EP530/77-501A, (January 1977).

Table 2: Progress of Degradation and Leachate Characteristics

Regime	Predominant Organics	BOD_5	pH	BOD_5:COD	Years
Aerobic					
|	Volatile Fatty Acids	5,000-20,000+	4-5	0.7	1st
Anaerobic	(mw < 500)	|	|	|	|
Acidic	|	|/	|	|	|
|	|	1,000-5,000	|	|/	|
|/	|/	|	|	0.5	|
Anaerobic,	Humic,	|	|	|	|
Methano-	Carbohydrate	|	|	|	|/
genic	Like Organics	|	|/	|	5th
|	(mw 5,000-	|	6-7	|	|
|	50,000+)	|/	|	|/	|
|	|	100-1,000	|	0.3	|
|	|	|	|	|	|
|	|/	|	|	|	|
|	Aromatic-,	|	|	|	|
|	Hydroxyl-,	|	|	|	|
|	Carboxyl-,	|/	|/	|/	|/
|	Fulvic-like	50-100		<0.1	10+
|	Organics				
|/	(mw 500-5,000)				

Source: Coulter, R.G.
Leachate Characterization. Proc. Leachate Treatment and Disposal: PCAO Seminar, Toronto, Ontario. March 4, 1991.

TOC is the measure of total organic carbon in the leachate. It is determined by measuring the amount of carbon dioxide that is produced when the carbon is completely oxidized. It gives the most reliable analysis of total organic material in the leachate.

The TOC measurement in the leachate is an indication of the total organic material in the waste. As a result, this will, in combination with BOD_5 and COD measurements, reveal the amount of potentially unreacted carbon after treatment.

The BOD_5 analysis measures the amount of oxygen that is consumed during the five days of the biochemical decomposition of the leachate. The result can also be used to determine if the leachate can be treated in a biological system or whether the toxicity is too high to allow treatment. A caution is that ammonia in the leachate will artificially elevate the BOD_5 readings.

COD measures the oxygen required to chemically oxidize all of the carbon compounds and other oxidizable materials. This is a quicker and simpler test than BOD_5 and gives an indication of the treatability of the leachate.

The VFA test measures the concentration of weak organic acids such as acetic, propionic and butyric acids. These acids are readily biodegradable in an aerobic treatment process. The analysis can indicate the age of the landfill as a lower VFA means an older landfill.

The ratio of BOD_5 to COD, as shown in Table 3, gives an indication as to how much of the organic matter can be removed from the leachate through biological treatment. Similarly, a high ratio of VFA to TOC indicates that the leachate came from a landfill that contains refuse which is biologically active under anaerobic conditions.

Table 3: Leachate Characteristics VS Age [10]

Parameter/ Ratio	< 5 years	5 to 10 years	> 10 years
COD (mg/L)	> 10,000	500 - 10,000	< 500
COD/TOC	> 2.7	2.0 - 2.7	< 2.0
BOD_5/COD	> 0.5	0.1 - 0.5	< 0.1

Morelli [10] developed leachate quality relationships from BOD_5 and COD data to estimate the age of the wastes in the landfill or more precisely its degree of stabilization (i.e. reduction of easily biodegradable organics and near completion of settlement).

2.4 Nitrogen Compounds

Ammonia-nitrogen (NH_3-N) and ammonium (NH_4^+-N), referred to as total ammonia-N, are commonly found in leachate. Total ammonia-N is a major end product of anaerobic decomposition of nitrogen contained in organic compounds. It can therefore be used as an indicator of the type and degree of degradation going on in the refuse. The ammonia-N is also a major water pollutant.

Organic nitrogen results can be used to indicate the level of biological degradation as they represent an intermediate step in the biological conversion of ammonia.

If nitrites (NO^-_2) and nitrates (NO^-_3) are found in the leachate then the refuse is degrading aerobically. The nitrite is the intermediate product of nitrification leading to nitrate.

A final test is the Total Kjeldahl Nitrogen (TKN). This is a combination of total ammonia nitrogen and organic nitrogen. The analysis results indicate the level of stabilization and the age of the landfill.

2.5 pH Value

pH measurements are conducted on a leachate sample to determine the measure of acidity or alkalinity. One of the reasons for the development of mineral encrustations is the presence of leachate at a pH level above 8.5. Mineral encrustations may occur in the pipes and other systems used in the transport or treatment of the leachate. Similarly, corrosion effects are commonly associated with pH levels below 6.5. Also, the lower the pH, the stronger will be the leachate, as more material will be dissolved into the liquid. Anaerobic bacteria generally operate in an acidic state whereas the aerobic bacteria generally prefer a neutral condition.

2.6 Quality Range

As noted previously, the quality of leachate varies significantly from site to site. As a result, the quality needs to be determined for each landfill before treatment processes can be evaluated.

Table 4 is a listing of typical characteristics and quality of landfill leachates found in Ontario. Reference can also be made to the examples presented throughout this report for more leachate characteristics.

Table 4: Summary of leachate characteristics for Ontario

Parameters*	No. of sites	Overall Range	Typical Range
pH (no units)	15	5.4-8.32	6-7
Alkalinity	13	137-11500	300-2000
Hardness	12	168-10460	400-2000
COD	13	<3-19000	150-6000
BOD_5	9	5-12500	50-4000
DOC	11	2.3-8000	4-500
TKN	7	0.44-2900	1-100
Ammonia	12	<0.10-2750	5-100
Nitrate	12	<0.01-39	<1-5
Nitrite	9	<0.02-8.1	<1
Sulphate	15	<1-940	<1-300
Phosphate	5	0.6-30	1-10
Aluminum	7	<0.01-1800	<0.01-2
Arsenic	1	0.01-0.04	0.01-0.04
Barium	6	0.068-3.6	0.1-2
Beryllium	4	<0.0005	<0.0005
Boron	7	0.022-376	0.5-10
Bromide	5	<0.5-37.4	<1-15
Cadmium	7	<0.005-0.02	<0.01
Calcium	15	18.9-3400	100-1000
Chloride	16	6-11600	20-2500
Cobalt	4	<0.01-0.08	<0.01-0.08
Copper	9	<0.008-54	<0.008-1
Chromium	10	<0.01-17	<0.01-0.5
Fluoride	5	0.25-244	5-50

* NOTE: All units in ppm unless otherwise noted.

Source: K.A. Vooro. Chemical Characteristics of Leachate from Ontario Landfill Sites, University of Waterloo Work Report, December, 1988.

2.7 Monitoring[3][4][6]

Many years ago, very little attention was given to the monitoring of sanitary landfill operations because:

a) landfill operations were often considered final disposal techniques for solid wastes. After they were covered and compacted, the operations were considered completed and final;

b) pollution potential of leachates generated in a landfill were not always known or considered;

c) there were no provisions by most municipalities to allocate any funds to solid waste activities to obtain meaningful monitoring data.

Today, regulatory authorities, including the Ministry of Environment and Energy, require monitoring in those situations where nuisance, environmental impact or health problems are possible.

Monitoring of any type involves some expense. Because of this, monitoring should be carefully planned to obtain meaningful data at a minimum cost.

Some of the following parameters could be monitored:

a) characteristics of leachate generated at the site;
b) chemical quality of ground water and surface water;
c) landfill surface settling rate;
d) erosion of cover soil from the site;
e) characteristics and approximate quantities of solid wastes deposited in the site;
f) quantity of leachate collected at the site;
g) rainfall quantity and dates:
h) performance of leachate control facilities.

Whenever possible, background data on the chemical quality of ground water and surface water should be documented. This will give an indication of any leachate migration at a later date.

A monitoring program should also determine if a leachate plume is being created below a landfill. If found, the direction and rate of movement should be determined. Any change of the leachate quality should also be determined. Additional information on the objectives, development and refinement of a monitoring plan can be found in Ministry's guidelines [95].

3.0 INFILTRATION CONTROL [3][4][6]

The first line of defence for leachate control is to reduce the formation of the leachate. The rate of water infiltration into the landfill is the predominant factor in the rate of leachate generation. A common leachate management strategy is to minimize the rate of leachate generation by minimizing the rate of water infiltration. Where rate of leachate generation is reduced, leachate strength is likely to be high for a longer period of time. Similarly, the concept of natural attenuation is to achieve leachate generation (and migration) which is less than the capacity of the surround soil to attenuate the leachate to acceptable levels. Hence minimized rate of infiltration of water is generally desirable.

Minimizing water infiltration is not the only strategy. Particularly for containment sites, higher rate of leachate generation is sometimes desired to promote rapid stabilization or aging of the landfill.

Water infiltration from precipitation can be reduced by:

a) application of daily and intermediate cover;
b) installation of a suitable cover system above the refuse;
c) cultivation of a suitable vegetation to help in evapo-transpiration and to reduce soil erosion;
d) installation of proper slope and grading on the landfill;
e) limitation of the size of the active operating area.

Water infiltration from ground water or surface water can be minimized by:

a) installing a perimeter drain around the landfill;
b) diverting surface water flow;
c) installing a subsurface collection system.

The minimizing of leachate can also be assisted by controlling the type of material deposited in the landfill, as for example by limiting the amount of wet or liquid wastes allowed.

Reduction or minimization of leachate production is not however always a goal at all landfills. New design and engineering approaches would develop landfills as large biological reactors, where leachate would become an active element.

4.0 TREATMENT [11]

Treatment options for leachate can take the form of:

a) total on-site treatment;
b) total off-site treatment, usually at a municipal sewage treatment plant;
c) partial on-site treatment with a final treatment at a municipal treatment plant.

The selection of any of the above options would depend on many factors related to technical and economic aspects of the situation.

Factors affecting total on-site treatment:

a) availability of space for construction of facilities;
b) type of treatment required;
c) quantity of leachate and its characteristics;
d) availability of power;
e) point of discharge.
f) availability of funds for costs (capital, installation, operation and maintenance)

Factors affecting total off-site treatment:

a) adequacy of existing sewage treatment plant capacity to handle extra organic loading (including Total Kjeldahl (TKN), total NH_3-N);
b) concentration of heavy metals, toxic organic compounds, and other contaminants;
c) pH of leachate;
d) transportation costs;
e) need for leachate pretreatment (availability of space and funds);
f) sludge disposal management practice at the plant.

4.1 Background

The characteristics of leachates vary widely from one landfill to the next, from place to place within some landfills, as well as from season to season and over the years. This makes the treatment difficult to describe and to control.

The treatment of leachate is also complicated by its characteristics. The selection of the treatment process and method of handling are determined by several factors such as:

a) leachate characteristics (organic and inorganic constituents);
b) leachate volume/rate;
c) discharge requirements: space available, proximity to nearby land uses;

d) cost effectiveness;
e) handling of process residuals;
f) air emissions.

There are several methods of controlling and treating leachate at a sanitary landfill site. These include:

a) natural attenuation: where natural attenuation is not appropriate or adequate by itself, leachate interception or collection system may be necessary;
b) leachate treatment by physical/chemical and/or biological processes;
c) leachate transportation and treatment off-site, for example at Water Pollution Control Plant (WPCP).

If leachate is sent to an off-site sewage treatment plant, pre-treatment may be required to:

a) avoid sewer use surcharges for over-strength wastes;
b) meet quality limits set by sewage plant owner.

If leachate is managed on site, then generally it will need to be treated to meet surface water discharge limits. Treatment and pre-treatment include the same general processes which are:

Biological treatment:

a) aerobic lagoons;
b) activated sludge plants;
c) rotating biological contactors;
d) anaerobic lagoons;
e) anaerobic digestion;
f) land treatment:
    - spray irrigation;
    - ridge and furrow;
    - overland flow irrigation;
    - rapid bed infiltration;
g) facultative lagoons;
h) wetlands.

Physical/chemical treatment:

a) chemical precipitation;
b) equalization;
c) neutralization;
d) membrane processes;

e) ion exchange;
f) activated carbon adsorption;
g) break-point chlorination;
h) chemical oxidation.

4.2 Attenuation[12] [13]

Attenuation is a process by which the level of the chemical contaminants in the leachate is reduced by mixing with uncontaminated water (dilution) or by interaction with the soil matrix.

When selecting new landfill locations, sites with natural attenuation are preferred, because leachate contaminants are naturally reduced to acceptable concentrations or naturally contained. Landfill design and operations based on natural attenuation are less complex than on engineered facilities.

Attenuation may take place through six major mechanisms:

a) mechanical filtration;
b) precipitation;
c) sorption;
d) dilution and dispersion;
e) microbial activity;
f) volatilization.

Mechanical filtration is the process of removing suspended contaminants in the leachate as it flows through the soil layer with suspended contaminants being trapped by the soil. The effectiveness of soil for straining or removing the suspended particles depends upon the type of soil, its structure and thickness of the layer.

Precipitation is a chemical reaction which converts contaminants into insoluble components which can be physically removed from the leachate. Precipitation is considered to be very important in the removal of heavy metals from leachate.

Sorption includes the processes of adsorption, absorption, desorption, and ion exchanges. Adsorption occurs when the soluble contaminants in the leachate become chemically bonded to clay textured particles, hydrous oxides and soil organics. The degree of adsorption will depend on soil properties such as the cation exchange capacity. Desorption may also occur with time and ion exchange will only achieve temporary removal of the exchangeable ions.

As the leachate moves through soil matrix, the above processes will remove generally (depending on the hydrogeology of the site) most of the heavy metals such as lead, arsenic, zinc, cadmium, and mercury.

Attenuation by **dilution and dispersion** reduces the levels of contaminants by mixing with greater volumes of ground water. The degree of attenuation achieved by this mechanism can be significant. However, the total mass of the contaminants moving into the ground water system is not changed. Only the concentration is reduced by mixing with more water.

Microbial activity involves the uptake and utilization of organic and inorganic contaminants by the micro-organisms in the soil. The pH of the leachate may be one of the indicators of the success of this technique.

Volatilization takes place when the contaminant in the leachate evaporates and moves into the soil medium above the water table. Only compounds with a low vapour pressure will be volatilized.

Studies in southern England[14] indicated that the unsaturated zone under a landfill can provide a degree of attenuation for the contaminants in the leachate. This was a major research investigation funded by the U.K. Department of Environment to investigate the attenuation capacity of semi-permeable soils to attenuate leachate contaminants. Conclusions were based on changes in the fatty acid concentrations in the water samples collected at various depths in the monitoring wells located strategically at the landfill site. Fatty acid concentrations of nearly 10,000 mg/L were measured initially in the leachate penetrating the unsaturated zone but these were reduced to below the detection limit of 5 mg/L at a depth of 3.0 m. At shallow depths where the highest concentrations were measured, fatty acids were reduced by at least 70 percent. These changes are said to have occurred without any reduction in the concentration of chloride. The researchers concluded that the presence of an unsaturated zone beneath a landfill provides opportunities for attenuation of organic constituents in the leachates by biological processes.

4.3 Land Treatment[15] [16]

Land treatment is defined as the controlled application of wastes or leachate on the land surface to achieve a specified degree of treatment. Treatment is provided through natural physical, chemical and biological processes occurring within soil and plant ecosystems. Odours from such treatment can be a problem and nuisance.

Land application can offer an economic and effective means of treatment and disposal of untreated or partially treated leachates. Its basic purpose is to reduce the levels of contaminants, as well as to recycle the nutrients and water components in the leachate for the productive use in agricultural or silvicultural systems while at the same time, reducing the levels of contaminants.

The treatment is provided as the leachate moves through the natural filter provided by the soil, plants and biological life. Part of the leachate applied is evaporated, plant transpirated and some contaminants used as nutrients, while the remainder returns to the hydrologic cycle by seepage into the ground water system. The volume of waste water is reduced by a combination of plant uptake, evapotranspiration, percolation and maximum contaminant loading on soil.

There are a number of different ways to apply leachate to the land in the irrigation systems. The method of application depends upon the soil, the type of crop, the climate and the topography. The three methods most commonly used are spray irrigation, ridge and furrow irrigation, and overland flow irrigation. These are shown in Figure 1 and their characteristics compared in Table 5.

Spray irrigation is the most commonly used and acceptable method. It is used in rolling topography and when the area is covered by crops or trees. Ridge and furrow application requires gently sloping ground with grass or row crop covering. Overland flow irrigation requires a flat area with a gentle slope covered in grass. A modification of this last method is termed rapid infiltration.

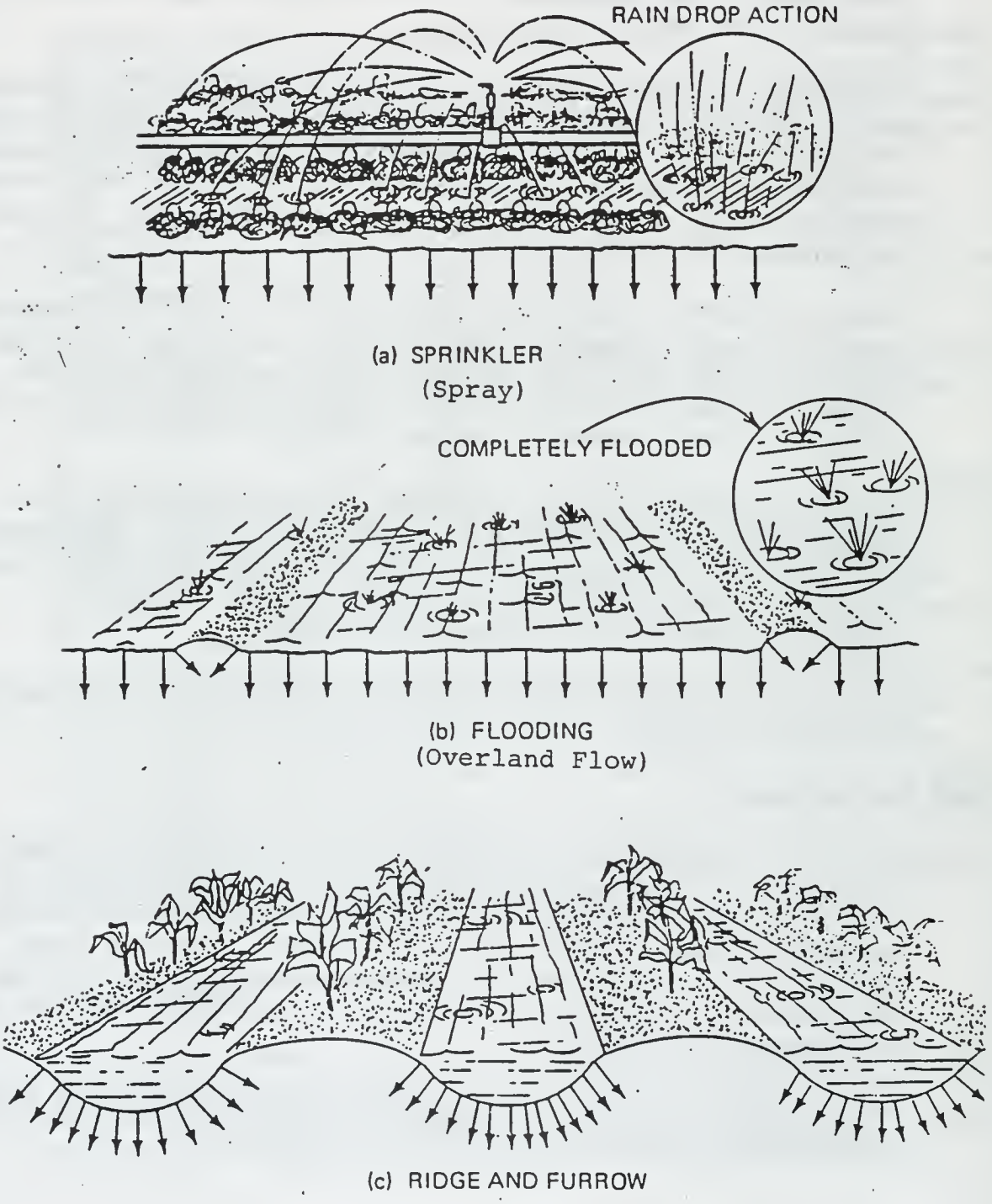
Each site will have its own physical characteristics that will influence the choice of the method of application.

4.3.1 Spray Irrigation

In this method, the leachate is sprayed above the surface of the ground to fall like rain on the site. The elements of a spray system include a pump or a source of pressure, a supply main, laterals, risers, and nozzles or sprinkler heads. The spray system can be portable or permanent, moving or stationary. The more modern equipment has become automated with a programable-timer to operate the system under controlled conditions. By adjusting the pressure and nozzle opening size, the rate of discharge can be varied.

The leachate used in the spray irrigation system must not contain any solids which are large enough to plug the nozzles or form a scale in the piping.

Figure 1: Types of Irrigation Systems



Source: Metcalf and Eddy. Wastewater Engineering: treatment, disposal, reuse. McGraw-Hill Inc., New York, N.Y., p.784 (1979).

Table 5: Comparison of Land Application Methods

Application Method	Spray Irrigation	Overland Flow	Rapid Infiltration
Annual Loadings (m/yr)	0.3 to <1.5	1.5 to 7.6	3.3 to 152
Ideal site conditions	°high evaporation °no ponding °large space	°no runoffs °gentle slope °high evaporation rate	°highly permeable °sand or gravel
Soil Type	°suitable for irrigated agriculture	°slow permeability °high water table	°highly permeable °sand or gravel
Effectiveness	°practical only during dry seasons	°depends on dry weather conditions	°depends on dry weather conditions
Limitations	°effective only during summer	°large area of land required °summer weather	°clogging problems
Minimum Treatment Required	°primary	°grit removal °pulverization	°primary
Problems	°runoff °ponding °kills vegetation	°runoff °groundwater contamination	°groundwater contamination °clogging
Costs (1981, not including power):			
(a) Capital	$69.88 per linear ft.	$10.54 per linear ft.	
(b) O & M	$7.87 per linear ft.	$5.84 per linear ft.	

Source: Lu, J.C.S. et al.[11] and Reed, S.C. et al.[15]

One of the most comprehensive studies[17] reported in the literature was conducted by the U.S. Department of Agriculture in Mercer County, West Virginia. Leachate was applied by spray irrigation on test plots with various species of deciduous trees, shrubs and ground covers. Some of the test plots were seeded with various forage grasses. General conclusions were that most of the trees were tolerant to the leachate. Most of the forage grasses were severely affected by excessive spraying but these seemed to recover when the application was reduced.

Spray irrigation is also used extensively for the disposal of landfill leachate in the southern part of England. Evaporation rates of 40 to 50 cm/year are reported[9]. Various application methods ranging from perforated pipes to heavy duty spray nozzles are used to disperse the leachate in grass covered lands. A dosage of 56,000 litres per hectare per day has been achieved in Cornwall (England) under the prevailing climatic conditions. This is equivalent to a spraying rate of 5.6 mm/day.

In Ontario, spray irrigation has been employed to disperse the leachate arising from a landfill site near Gravenhurst. The spray irrigation method was suggested as a remedial method to prevent leachate contamination of Lake Muskoka. The landfill site in the Township of Muskoka Lakes near Gravenhurst was the first known location in Ontario where a spray irrigation system was used on a relatively large scale to treat leachate. This practice was initiated in 1981 after the early attempts to disperse leachate by percolation though infiltration trenches had proved unsatisfactory.[19]

Initially, the spray irrigation of the leachate was started with a single, portable nozzle which was relocated periodically in the forested area. Within two years, it was expanded to a fixed 6-nozzle system. Because of the soil saturation and ponding problems, the system was expanded to 24 nozzles and eventually to a network with 72 nozzles covering a spray area of 4.3 hectares in the forested area, during the summer of 1985.[18]

In 1986, the Ministry of Environment engaged the services of the University of Guelph to study the environmental impact of the leachate applied in the forested ecosystem[19] because of visible damage and decline which were noticed on some of the trees and vegetation exposed to the leachate sprays. The report concluded that spray irrigation as a method of leachate management at that particular site was not considered an environmentally sound long-term solution. The reasons given were:

a) disposal of large volumes on limited land area caused waterlogged conditions;

b) the soils did not have suitable physical and chemical properties for an effective operation of a spray irrigation system;

c) the soils did not have the capability to retain and attenuate the leachate.

In another study[20], the University of Guelph demonstrated that significant volumes of leachate can be consumed by the evapotranspirational process if applied onto an agricultural land with both wood vegetation as well as grasses. In the same study conducted to evaluate phyto-toxic effects and determine evapotranspirational demand, it was concluded that:

a) leachate irrigation can be beneficial to plant growth;
b) leachate consumption was a function of moisture demand of the plants;
c) some species of grasses were resistant to phytotoxic effects of leachate contaminants.

The application was the function of four factors which included:

a) atmospheric uptake during the particular time of the season;
b) any precipitation events in a 24-hour period;
c) conductivity of the soil cap;
d) moisture content of the underlying soil in the application area.

Advantages of spray irrigation include:

a) can be an effective method for handling leachates from landfills located in remote areas;
b) leachate can be applied on grassland or forested areas;
c) application rates and timing can be controlled;
d) this method can be used on almost any kind of topography;
e) soil layer can be utilized for biological treatment and filtration system;
f) enhanced vegetation growth.

Disadvantages include:

a) high costs for spray equipment;
b) large areas in the vicinity of the landfill site may be required;
c) possible contamination of surface and ground waters from runoffs;
d) success depends on weather conditions;
e) labour requirements for maintenance;
f) potential odour and aerosol problems;
g) erosion problems if excessive spraying;
h) buildup of heavy metals and sodium in the soil.

4.3.2 Ridge and Furrow Irrigation [15]

In the ridge and furrow method, the land must be relatively flat. The ground is groomed into alternating ridges and furrows, the width and depth varying with the amount of leachates to be disposed of and the type of soil. The leachate is allowed to flow by gravity in the furrows and seep into the ground. The rate of infiltration into the ground will determine the amount of leachate that can be applied. The furrows must be allowed to dry out after each application of leachate so that the soil pores do not become clogged.

A limitation of this method is the biological conversion of nitrogen compounds (ammonia-nitrogen, ammonium) to nitrate which, in turn, leaches into the groundwater. Also, there is a danger that phosphorous and heavy metals may exceed the retention capacity of the soils. The negative effects of this method of land treatment are potential soil and groundwater contamination.

4.3.3 Overland Flow Irrigation[16]

Overland flow irrigation is shown in Figure 2 as controlled application of leachate across grass-covered, uniformly graded, gentle slopes of land with relatively impermeable soils. This method is said to be still widely used for the disposal of various wastewaters particularly within the food processing industry. It has been employed for the treatment of municipal wastewaters in England and Australia.

Overland flow system can be considered for sites with sloping terrains in the range of 1 to 12 percent grades. The site should be covered with a healthy growth of perennial grasses to provide slope stability and erosion prevention. The vegetation also contributes to the removal of nutrients and other contaminants from the leachate. It also plays an important role on the rates of evapotranspiration.

Although no overland flow programs were located in the literature for leachate treatment, overland flow irrigation represents another means of treating leachate.

4.3.4 Rapid Infiltration Process[15][16]

Land treatment using the rapid infiltration (RI) process refers to the controlled application of pretreated leachate to lands with high permeability (i.e. sand or loamy sands) by flooding in basins or trenches. The leachate is attenuated by natural processes involving biological, chemical and physical interactions taking place in the soil matrix near the surface.

As shown in Figures 3 and 4, the liquid enters the groundwater system by infiltration and moves laterally away from the application site.

Because the RI process involves physical, chemical and biological reactions, it requires adequate retention time for the leachate in the soil matrix to attain proper levels of treatment. The application of leachate must be intermittent to allow aerobic conditions to be maintained or restored within the soil. For the treatment of landfill leachate, there are two sites where this technology has been tried in Ontario and another site is reported in use in Sweden[21].

A form of RI system was first tried by the Township of Muskoka Lakes in 1979 as a remedial measure to control and divert landfill leachate from Lake Muskoka. The leachate was pumped into a 76.2 m collection trench and a 91.4 m culvert and allowed to infiltrate into the soil. In spite of the sandy soil and expansion of the trench size, the system did not perform satisfactorily because the "leachate infiltration into the soil was not fast enough to keep up to the pumping flow." Although the report did not state the nature of the problem, it is suspected that the surface of the infiltration bed became clogged with suspended matter in the leachate.[18]

Another RI bed system was installed and placed into operation at the Durham Regional Landfill Site during late 1985 (Personal Communication with J. Dulny, MOEE Central Region, December, 1992). The system consisted of two beds located side by side and situated approximately 95 m from a creek. The dimensions of the two infiltration beds were 45 m x 3 m wide. The beds were located at an elevation of approximately 10 m above the creek bed.

Two problems were identified. One of them was soil clogging as the beds had to be cleaned out annually. The second problem was the potential threat of leachate migration to the water table. This was apparent by the observations of small trickles of leachate breakout in the flood plain along the creek bed during 1989. To remedy this situation, a trench was excavated along the creek to install a leachate collection system. The seepage of leachate and groundwater is pumped and recycled to the filtration beds.

Advantages of the RI process include:

a) low level technology;
b) low capital and operating costs;
c) minimal operational monitoring.

Figure 2: Overland Flow

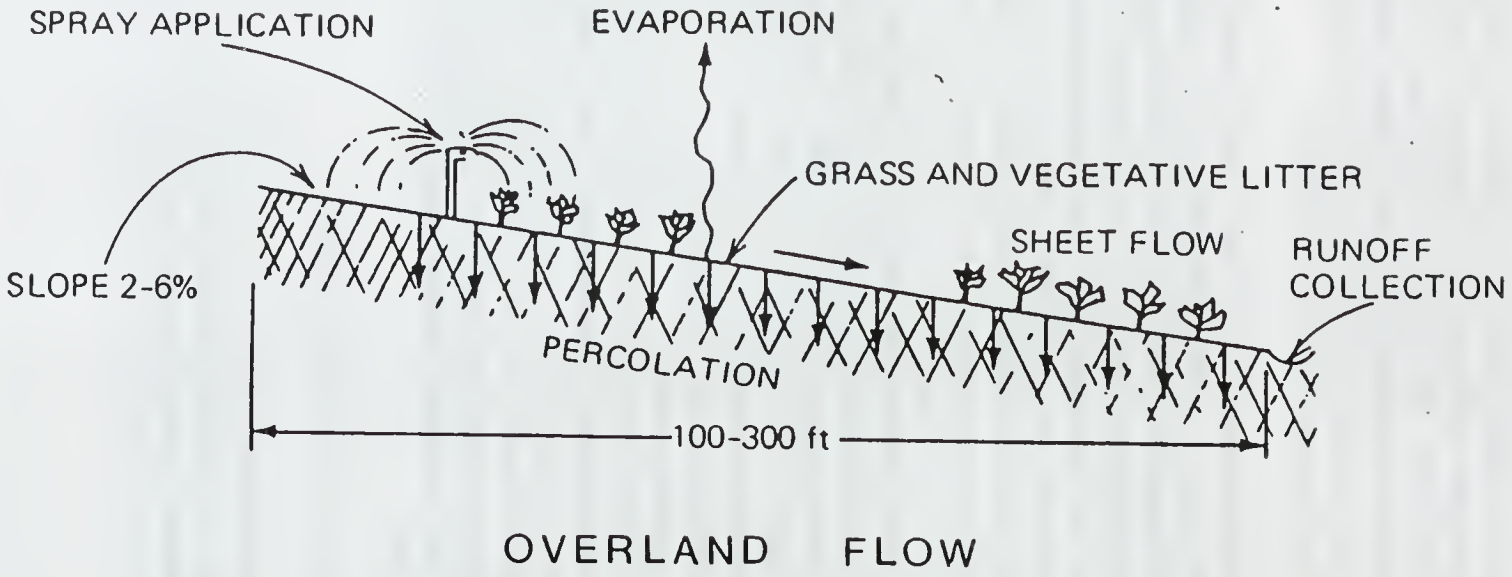
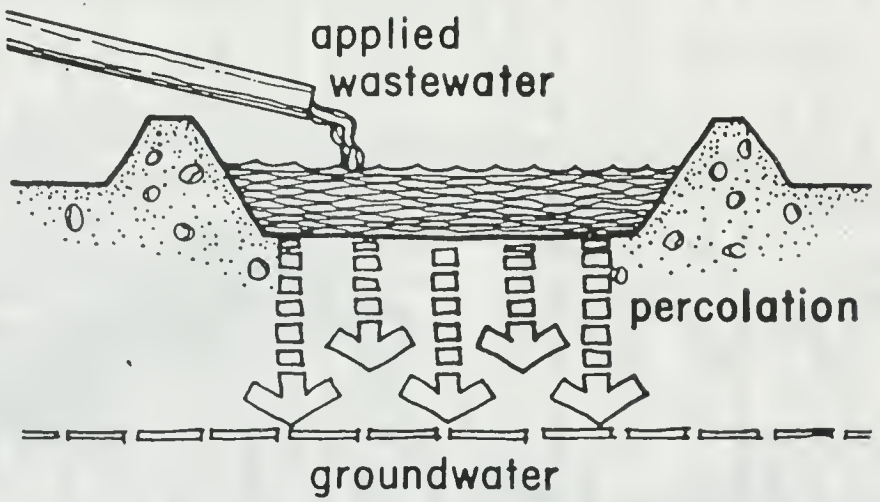
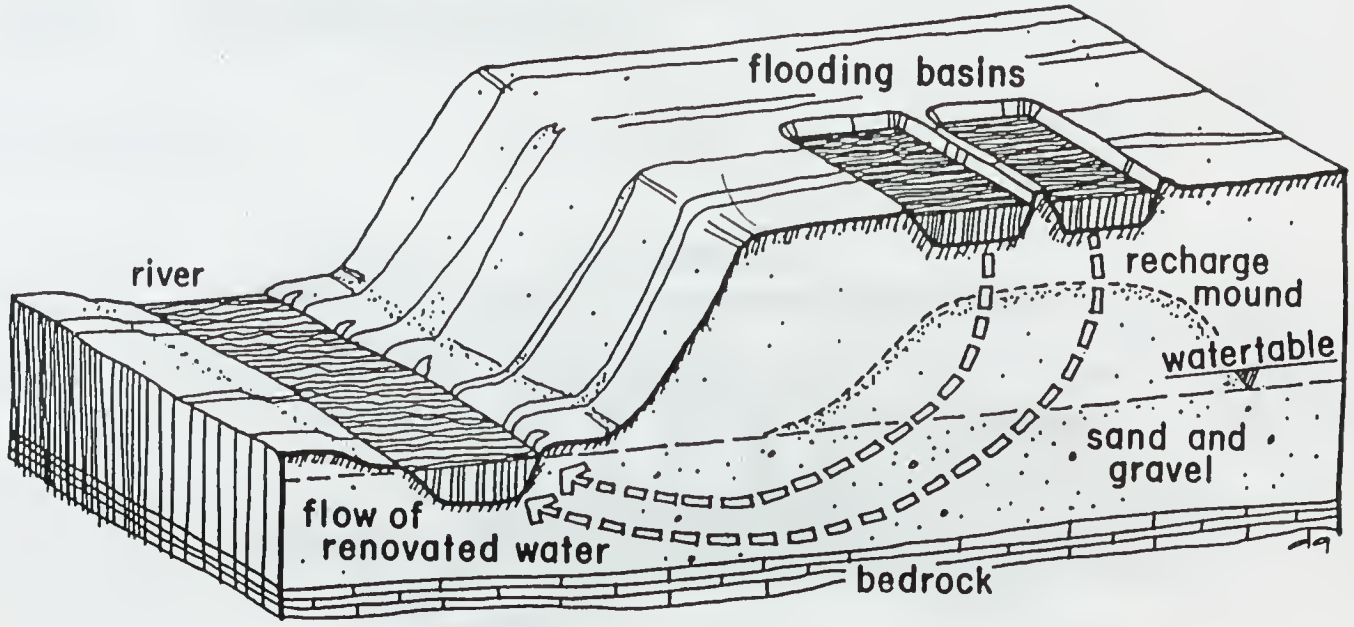


Figure 3: Rapid Infiltration



Source: Rapid Infiltration Design Manual,
Alberta Environment and City of Red Deer,
Alberta, 1981.

Figure 4: Operation of a Rapid Infiltration Bed



Source: Rapid Infiltration Design Manual (p.2)
Alberta Environment and City of Red Deer, 1981.

Disadvantages include:

a) possible odour problems;
b) low infiltration rates for size of sites available;
c) potential for groundwater contamination (limitations under Reasonable Use Policy 15-08 [94]);
d) frequent trench cleaning may be required;
e) unproven in Ontario for leachate.

4.4 Leachate Recirculation

Leachate recirculation or recycling involves the collection of the leachate from the bottom of the landfill and the distribution of the liquid onto or into the top of the landfill. The leachate may receive some pre-treatment depending on local conditions. Leachate recirculation was developed primarily as an emergency measure to alleviate leachate disposal problems while a more effective long term solution was found.

In leachate recirculation, the landfill itself is used as a natural bioreactor. The recycling of leachate in this manner provides suitable moisture conditions within the landfill refuse to stimulate biological activity to decompose organic materials contained in the wastes. This helps to promote a more rapid biological stabilization of the landfill.

The leachate is collected in a storage lagoon and normally recirculated over the landfill site by pumping through a number of pipes laid over the landfill cover. The pipes are perforated on their upper side at regular intervals to allow leachate to run onto the cover for infiltration into the refuse. Other options include placing a number of sprinkler jet nozzles strategically so that the leachate can be sprayed uniformly over the entire surface of the landfill, or by using injection wells so that the leachate is recycled directly into the refuse.

The method will depend on the ease with which the pump and sprinkler system can be installed. The availability of electrical power at the site is also an important consideration. Its success will also depend on the ease at which the leachate can infiltrate through the soil cover of the landfill.

Leachate recirculation has been a subject of research by several workers in Europe and the United States. During the 1970s, Pohland [22] found that recirculation of leachate could stimulate biological activity in the municipal waste landfill and stabilize the buried wastes in as short a time as two years after the landfill's closure. He also found that he could control the process of attenuation in the landfill cover to maximize contaminant reduction. He called this technique a "controlled stabilization".

Pohland advised that leachate should be applied intermittently and increased slowly after the initial period following the closure of the landfill. This procedure provides a period of acclimation for the biological activity to become firmly established. It also helps to prevent the buildup of excessive volatile acids and inhibitory pH conditions.[23]

In the meantime, leachate recirculation has been practised and tested on large scale landfills in the Federal Republic of Germany[24] during the early part of the 1980s.

There are conflicting reports in the literature regarding the benefits of leachate recirculation. Studies in Germany have shown that leachate recirculation may result in a sharp decrease in the leachate organics. This results from an increased moisture level in the landfill improving the biological environment and biological accessability to contaminants.

Doeden and Cord-Landwehr[25] felt this practice may increase the risk of leachate seeping into adjacent soil and groundwater. Another potential risk is higher concentrations of salts and heavy metals as a result water loss by evapotranspiration when the leachate is spread over the landfill cover.

Maris et al.[26] found after a 30-month study that although the organic strength may decrease during recirculation, there was very little tendency for the chloride and ammonia to decrease with time. They conclude that recirculation of leachate by itself does not provide a complete treatment even though there were significant reductions in volume and strength of the leachate.

In addition to this, Otieno [27] found that recirculation of leachate in the landfill over a given period of time resulted in good quality leachate with lower concentrations of contaminants. In some cases, the leachate quality had improved to such an extent that it could be discharged into the existing sewers without incurring sewer surcharges. However, he warned that recirculation may impede the development of methanogenic conditions in the landfill and thus slow down and even eliminate the production of methane.

If leachate recirculation is operated under saturated conditions within the landfill, the leachate is likely to have a higher polluting strength.

Leachate recirculation was included in the design and operation of the Keele Valley Landfill Site,[28] [29] Maple, Ontario. The landfill receives approximately 1,000,000 tonnes of wastes annually from Metropolitan Toronto. The purpose of leachate recirculation is to stabilize the refuse in the landfill in a much shorter time than normal and enhance gas production while reducing the strength of the leachate for discharge into the sanitary sewers.

After a preliminary test program in 1986, it was concluded that injection wells were the most practical method for leachate/moisture recirculation. Of the five methods studied, the Consultants stated several advantages for the use of injection wells.

a) most effective vertical and horizontal distribution of moisture;
b) limited potential odour problems;
c) low maintenance;
d) minimum site interruptions;
e) no disruptions from inclement weather;
f) only practical method of leachate recirculation on steep slopes.

At Keele Valley, the leachate is collected and pumped with water from the purge wells into the buried refuse through injection wells placed strategically over the landfill.

Each injection well consists of a 50 mm diameter x 10 m long schedule 40 polyethylene pipe wrapped in filter cloth and placed inside another 250 mm diameter polyethylene pipe packed with 20 mm washed stone.

The 50 mm pipe is perforated for 3 m at the bottom end and the other end is connected to the feeder line to the leachate pipe. The outer pipe is sealed at the surface end with 0.3 m of bentonite clay and perforated with 10 mm diameter holes. (See Figure 5).

Some of the concerns expressed about leachate recirculation at the Keele Valley Landfill Site were as follows:

a) unproven technology for large scale operation;
b) addition of large volume of moisture over a large site area;
c) operation of landfill equipment on or in close proximity to leachate recirculation area;
d) freezing problems in the winter;
e) problems with gas collection;
f) leachate short-circuiting;
g) gas and odour problems.

Stegmann[30] suggested that leachate recirculation should be optimized to avoid anaerobic conditions in the landfill. It should be practised only with pretreated leachate and the application rate should be the same as the evaporation rate.

Although recognizing the benefits of moisture addition to landfills by leachate recirculation, Morelli [10] stated that there was a scarcity of data from full-scale demonstration projects to confirm that the investment for leachate recirculation system was worthwhile.

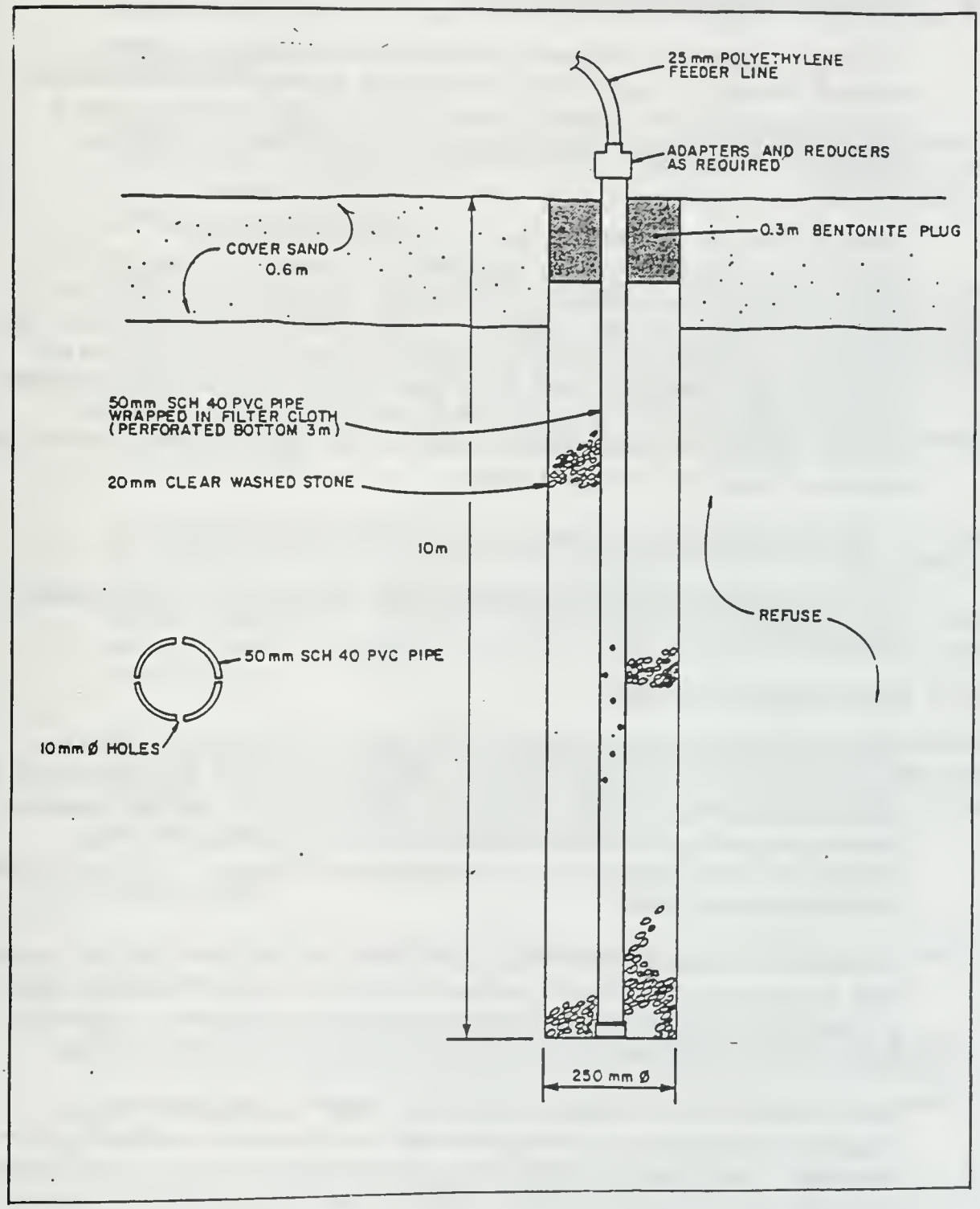
Advantages of leachate recirculation include:

a) simplicity;
b) low cost for equipment and maintenance;
c) no need for transportation of leachate off-site for treatment;
d) leachate volume can be reduced at various levels by evapotranspiration and retention by unsaturated refuse in the landfill;
e) no additional land space required for treatment facilities;
f) significant reduction in terms of BOD_5 and pH can be achieved if leachate is derived from young landfills;
g) can accelerate biological stabilization if the landfill contains large quantities of biodegradable organic materials;
h) may help to ease the threat of contamination for surface and ground waters;
i) oxidizes and precipitates some inorganics such as iron.

Disadvantages include:

a) applicable mostly at landfill sites where electric power is readily available;
b) no decrease in the concentrations of heavy metals and inorganic constituents in the leachate;
c) continued recirculation may lead to a build-up of chlorides, sulphates and dissolved solids which may affect evaporation rates;
d) surface ponding;
e) no removal of COD especially leachates from older landfills;
f) increased hydraulic loadings may cause ground water contamination;
g) may result in surface runoff;
h) may introduce oxygen into an anaerobic landfill and have inhibitory effects on organic decomposition;
i) potential odour problems.

Figure 5: Typical Injection Well


25 mm POLYETHYLENE FEEDER LINE
ADAPTERS AND REDUCERS AS REQUIRED
0.3m BENTONITE PLUG
COVER SAND 0.6m
50mm SCH 40 PVC PIPE WRAPPED IN FILTER CLOTH (PERFORATED BOTTOM 3m)
20mm CLEAR WASHED STONE
10m
REFUSE
50mm SCH 40 PVC PIPE
10mm Ø HOLES
250 mm Ø

Source: Metropolitan Toronto Dept. of Works. Accelerated landfill stabilization: design rationale, Keele Valley landfill site. Conestoga-Rovers & Assoc., Waterloo. (Unpublished report, August, 1987).

4.5 Physical/Chemical Treatment of Leachate [11]

Various physical/chemical treatment processes have been applied to leachate treatment. Physical or chemical treatment processes may be particularly useful in treating leachates from older landfills where the biodegradable organic content is negligible or as a polishing step for leachates previously treated by biological methods.

However, at the new leachate treatment plant for the City of Sarnia [31], physical/chemical pretreatment was considered as a necessary requirement for the success of the biological treatment of the leachate. During the pilot studies, the leachate was found to be "old" and difficult to treat biologically. Because of its high alkalinity (3,000-5,000 mg/L) along with high concentrations of calcium, iron and magnesium, the leachate had a tendency to form inorganic precipitates that interfered with the oxygen transfer in the aeration basin. This minimized the biological treatment efficiency so physical/chemical treatment was added to form and remove the precipitates ahead of the biological section.

A more detailed description of this plant can be found in the Appendix.

Some of the physical/chemical processes that have been reported in use for leachate treatment are described below:

4.5.1 Precipitation and Coagulation

Chemical precipitation and coagulation can be utilized to remove iron, colour and suspended solids from leachates. Lime with dosages of over 300 mg/L can be used to remove iron and colour (see Section 4.5.3). Sodium sulphide[32] has been reportedly used for precipitating iron found in leachate. However, iron removal by this technique can only be achieved at very high dosages (1000 mg/L). Its effect on other constituents was negligible.

Coagulation with alum or ferric chloride can remove iron and colour but is of limited value in removing COD, chloride, hardness and dissolved solids. Results are highly pH dependent. Unfortunately, large chemical dosages are required to achieve the desired results and this may lead to the production of a large volume of sludge.

After reviewing studies of several researchers, Ehrig[33] concluded that chemical coagulation using lime, iron and aluminum salts was not a suitable method for the treatment of high strength leachates. This was because the organics in these leachates are mostly volatile fatty acids with low molecular weights which cannot be removed by precipitation.

A general conclusion of physical chemical pretreatment of leachates by the use of coagulating/flocculating agents is that they produce a minimal decrease in the concentrations of dissolved organics and heavy metals except at high pH level.

4.5.2 Equalization[34]

Equalization is primarily a technique employed for on-site treatment of industrial waste effluents. Waste streams are collected and retained in a storage basin so that any fluctuations in flows and strengths can be smoothed out to give an effluent of a relatively uniform consistency.

Because leachates have similar variations, the use of equalization basins can be used to level the flow of the leachate to a treatment facility. This helps to avoid any shock loadings and allow any processes involving automated chemical feed to operate with minimal disruptions. Equalization can be an essential part of the design of an on-site leachate treatment system. The absence of a suitable equalization pond was responsible for the failure of some of the early leachate treatment systems constructed about 30 years ago.

Equalization will permit any pretreatment option to be inserted into the process train. For example, the pH of the leachate can be adjusted easily, if necessary, prior to the main treatment process. At the Al Turi Landfill in Goshen, New York[35], the leachate is equalized in a lagoon and the pH is adjusted to approximately 10 to allow the heavy metals to precipitate. The lagoon effluent is then pumped into the leachate treatment facility.

Equalization can help to improve the performance of downstream leachate treatment processes which may be affected by flow variations. This could be any one of the following: carbon adsorption, biological treatment, chemical precipitation, chemical oxidation, membrane filtration or ion exchange.[36]

4.5.3 Lime Treatment

Lime can be used for clarification or turbidity removal, pH adjustment and heavy metals removal.

Lime is a highly alkaline chemical which consists mainly of calcium and oxygen. It is a relatively inexpensive chemical if required in large quantities. For leachate treatment, lime in the form of quicklime, CaO or hydrated lime $Ca(OH)_2$ usually is used.

By adding a sufficient dosage of lime to obtain a solution pH of 12, it is possible to reduce the turbidity by 98 percent. Studies by Shukrow[37] and others have indicated that the high COD levels can be reduced if the leachate is treated with high dosages

of lime. Leachate with 17,000 mg/L COD, when dosed to a concentration of 2,800 mg/L lime, was reduced to 1,500 mg/L COD at a pH of 10.8. Total suspended solids reduction with lime was reported to be greater than 86 percent. The total solids removal was not significant with reductions varying from 0 to 20 percent. In one case,[38] there was a slight increase in the total solids. The same study reported good iron levels reduction of over 98 percent.

Lime treatment is also a cost effective method of controlling hydrogen sulphide emission from leachates. Sufficient lime is added to raise the pH of the leachate to 10 or higher to help keep the sulphide in solution. Bacterial activity is inhibited and the formation of hydrogen sulphide by the microbes is prevented.

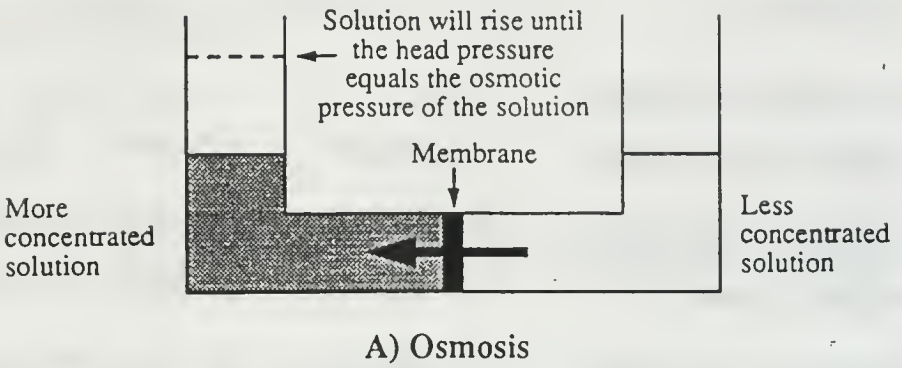
4.5.4 Membrane Processes

Membrane processes such as electrodialysis, reverse osmosis (RO) and ultrafiltration have been suggested as a polishing step for leachate after biological treatment. Researchers have found that reverse osmosis was effective in the removal of COD and dissolved solids in leachate treatment after biological treatment.[39][40][41] The concept of reverse osmosis is illustrated in Figure 6: when pressure is applied water is forced through the membrane while higher molecular weight organics cannot pass through. The contaminants are therefore concentrated into a smaller flow of leachate. Concentrate can be recycled into the landfill. Much of the work on the application of the RO process for leachate treatment reported in the literature has been conducted on a laboratory scale. One of the earliest studies with RO was conducted by Chian and de Walle[39] in the United States. They were able to achieve high total dissolved removal efficiencies of 85 percent to 99 percent. The removal efficiency was dictated by membrane type, operating pH and pressure.

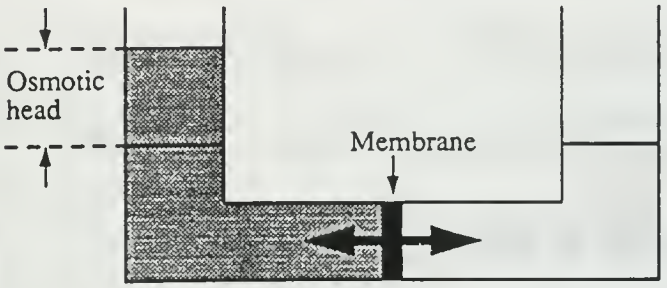
A Ministry funded research project [41] compared the costs of leachate treatments between activated sludge and combined treatment trains of chemical precipitation / microfiltration / reverse osmosis. The estimated capital and operating costs for 3 sizes of reverse osmosis facilities are noted in Table 6. The data assume that the leachate has been pretreated by microfiltration to reduce heavy metal and suspended solids concentrations. Reverse osmosis concentrate would be sent for further treatment and permeate could be sent to a local watercourse. The capital and operating cost estimates for the pretreatment are in Table 7 while recirculation of concentrate to the landfill has estimated capital and operating costs listed in Table 8.

Total treatment cost for a complete treatment system (i.e. pretreatment by precipitation / microfiltration and reverse osmosis final treatment) including amortization, installation and operating costs were estimated to be in the range of $4.14 to $5.86 (Canadian) per m^3 (1,000 litres) of leachate treated (see Table 6 and Table 7).

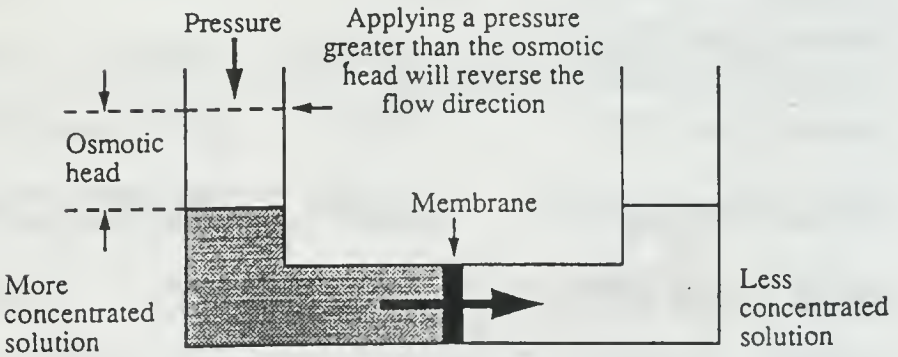
Figure 6: Concepts of Reverse Osmosis


Solution will rise until the head pressure equals the osmotic pressure of the solution
Membrane
More concentrated solution
Less concentrated solution

A) Osmosis



B) Equilibrium



Source: Field demonstration of membrane technology for treatment of landfill leachate. MOEE RAC Project No. 439c, p.17, December 1991.

TABLE 6: Capital and Operation Costs for Reverse Osmosis

Capacity (litres/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
CAPITAL COSTS (1990 CND $)			
Reverse Osmosis System	$38,850	$ 58,420	$ 73,610
Total Equipment Costs	$38,850	$ 58,420	$ 73,610
Installation Costs	$42,735	$ 64,262	$ 80,971
TOTAL CAPITAL COST	$81,585	$122,682	$154,581
OPERATING COSTS (1990 CND $/YR)			
RO Membrane Replacement (Membrane Life of 2 yr.)	$ 3,344	$ 6,687	$10,031
RO System Power (HPx0.746x24x365x$0.06/KW)	$ 3,919	$ 7,055	$ 9,798
Labour (1;1.5;1.75hr/day @ $45/hr)	$16,425	$24,638	$28,744
Maintenance	$ 1,943	$ 2,921	$ 3,681
YEARLY OPERATING COSTS	$25,631	$41,301	$52,254
TOTAL COSTS (1990 CND $/yr)			
Amortized Capital Costs (10yr @ 11%)	$13,869	$20,856	$26,279
Operating Costs ($/yr)	$25,631	$41,301	$52,254
TOTAL YEARLY COSTS	$39,500	$62,157	$78,532
Cost per 1,000 litres	$1.97	$1.55	$1.30

Sources: Field Demonstration of Membrane Technology for Treatment of Landfill Leachate, Environment Ontario, RAC Project No. 439c, December 1991.

TABLE 7: Capital and Operating Costs for Precipitation/Microfiltration

Capacity (litres/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
CAPITAL COSTS (1990 CND $)			
Reverse Osmosis System	$18,000	$ 23,000	$ 26,000
MF System	$66,250	$115,100	$169,300
Filter Press	$27,900	$ 34,400	$ 48,000
Total Equipment Costs	$112,150	$172,500	$243,300
Installation Costs	$123,365	$189,750	$267,630
TOTAL CAPITAL COST	$235,515	$362,250	$510,930
OPERATING COSTS (1990 CND $/YR)			
Precipitation Chemicals (Lime at $0.1/kg)	$ 1,004	$ 2,008	$ 3,011
MF Membrane Replacement (Membrane Life of 3 yr.)	$ 7,153	$14,306	$21,459
MF System Power (HPx0.746x24x365x$0.06/KW)	$ 7,839	$15,678	$19,597
Labour (1;1.5;1.75hr/day@$45/hr)	$16,425	$24,638	$28,744
Maintenance	$ 5,608	$ 8,625	$12,165
YEARLY OPERATING COSTS	$38,028	$65,253	$84,976
TOTAL COSTS (1990 CND $/yr)			
Amortized Capital Costs (10yr @ 11%)	$40,038	$61,583	$86,858
Operating Costs ($/yr)	$38,028	$65,253	$84,976
TOTAL YEARLY COSTS	$78,066	$126,836	$171,834
Cost per 1,000 litres	$3.89	$3.16	$2.84

Sources: Field Demonstration of Membrane Technology for Treatment of Landfill Leachate, Environment Ontario, RAC Project No. 439c, December 1991.

TABLE 8: Capital and Operating Costs for recirculation and Irrigation

Capacity (litres/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
CAPITAL COSTS (1990 CND $)			
Leachate Storage	$ 5,000	$ 7,500	$10,000
Distribution Pump & System	$ 5,000	$ 6,500	$ 7,500
Total Equipment Costs	$10,000	$14,000	$17,500
Installation Costs	$16,000	$22,400	$28,000
TOTAL CAPITAL COST	$26,000	$36,400	$45,500
OPERATING COSTS (1990 CND $/YR)			
Labour (.75;1;1.25hr/day@$45/hr)	$12,319	$16,425	$20,531
Maintenance	$ 1,000	$ 1,400	$ 1,750
YEARLY OPERATING COSTS	$13,319	$17,825	$22,281
TOTAL COSTS (1990 CND $/yr)			
Amortized Capital Costs 10yr @ 11%	$ 4,420	$ 6,188	$ 7,735
Operating Costs ($/yr)	$13,319	$17,825	$22,281
TOTAL YEARLY COSTS	$17,739	$24,013	$30,016
Cost per 1,000 litres	$0.88	$0.60	$0.50

Sources: Field Demonstration of Membrane Technology for Treatment of Landfill Leachate, Environment Ontario, RAC Project No. 439c, December 1991

In an earlier study done by the same firm, chemical precipitation (involving lime-soda process and microfiltration) removed heavy metals and suspended solids to prepare the feed for the reverse osmosis. Reverse osmosis was successful in removing 98 percent of the dissolved inorganic solids and also 98 percent of dissolved organics in the leachate. Solids from the microfiltration are dewatered in a plate and frame filter with resulting solids being solidified and/or landfilled. Reverse osmosis concentrate would be recycled into the landfill. Other studies were conducted at Manhattan College by Slater et al[42] on high strength landfill leachate. They found that pretreatment of the leachate with lime helped to eliminate dispersed oil particles and colloidal matter which tended to foul the membranes. They reported a 98 percent removal of dissolved solids in the pretreated leachate and well over 50 percent removal of organics as measured in terms of TOC and COD.

In Canada, Environment Canada has investigated the application of RO at the Gloucester landfill site using pilot plant equipment[43]. This study demonstrated the efficacy of RO process to remove low molecular weight organics from heavily contaminated leachate.

One of the major drawbacks with the RO process, other than very high treatment costs, is that the RO membranes are susceptible to fouling by the formation of biological slimes, scale deposition, plugging by colloidal particles and metal oxides. Pretreatment to remove solids is needed before reverse osmosis treatment of leachate.

In the Federal Republic of Germany[44][45] the state-of-the-art technology for leachate treatment involves the use of RO in combination with anaerobic pretreatment and in some cases, biological treatment with nitrification and denitrification is included in the process train.

The use of RO along with biological pretreatment produces a sludge that is less expensive to dispose than the sludge resulting from the precipitation/coagulation and activated carbon treatment process. This is primarily due to the larger volume of sludge from the latter process.

Advantages of using reverse osmosis include:

a) high quality effluent;
b) low sludge production;
c) removes both organic and inorganic dissolved solids;
d) modular equipment design.

Disadvantages include:

a) membrane fouling by solids and biological growth;
b) very high capital and operating costs;
c) low removal efficiency for low molecular weight organics and nitrogen compounds;
d) not adaptable to varying flow rates;
e) pretreatment of feed generally required;
f) scaling problems;
g) production of a concentrate that needs to be disposed of.

4.5.5 Ion Exchange[36]

Ion exchange refers to the reversible interchange of ions between a solid and a liquid. The ion exchange solid media are either naturally occurring materials (zeolites, greensands and clays) or synthetic organic products such a resins. Spent ion exchange media can be regenerated by washing with an excess of electrolyte. Ion exchange is used primarily to remove dissolved inorganics when a high quality effluent is required. It is widely employed for domestic water softening, demineralization of the boiler feed water and treatment of metal electroplating wastes.

For leachate treatment, it is likely to be applied in the final polishing stage for the removal of any contaminant which may cause a undesirable impact if discharged onto the receiving water. Ion exchange can be utilized for the removal of wide range of inorganics including metals, halides and cyanides. It is not recommended for any leachate containing over 2,500 mg/L of dissolved solids. This is because the high concentrations of dissolved solids cause rapid exhaustion of the ion exchange resins and escalate the cost of regeneration.

Prior to ion exchange, the leachate needs to be clarified by coagulation / flocculation / sedimentation to remove suspended solids and non-aqueous liquids (oil and grease). This is to prevent problems of fouling and plugging of the resin beds. In practice, the leachate is usually processed through physical/chemical treatment followed by biological treatment.

4.5.6 Activated Carbon Adsorption[46][48]

Treatment with activated carbon involves the removal of selected organic or inorganic contaminants from the leachate by adsorption by physical or chemical forces onto the carbon. Adsorption by activated carbon is a well-established technology employed extensively in the purification of industrial and municipal water supplies as well as in the treatment of wastewaters from various industrial and municipal sources.

Two types of carbon treatment systems are generally in use. The most common system involves the continuous flow of wastewater through a column or filter bed containing granular carbon. The other system, less widely used, involves batch treatment with powdered activated carbon treatment mixed as a slurry with the leachate. For large applications, carbon can be regenerated for reuse. For small applications, and those using carbon slurry, the spent carbon materials are disposed of in the landfill or incinerated.

The success and effectiveness of carbon adsorption depend on a number of factors[46]. These include:

a) carbon characteristics:
   - surface area;
   - pore structure and size distribution;
   - particle size;
   - surface polarity;

b) contaminant characteristics:
   - solubility;
   - molecular size;
   - ionization;
   - polarity;

c) liquid characteristics:
   - temperature;
   - pH;
   - presence of other solutes;
   - dissolved solids.

The ease with which certain compounds or substances can be removed from the leachate depend on the effect of molecular structure and other properties such as size, polarity and absorbability.

Activated carbon can effectively remove a wide range of compounds which include:

a) chlorinated hydrocarbons;
b) organic phosphorus;
c) carbonates;
d) polychlorinated biphenols (PCBs);
e) phenols;
f) benzenes;
g) pesticides such as aldrin, dieldrin, endrin, DDE, DDT and toxaphene;
h) inorganic ions listed in Table 9.

The suitability of activated carbon treatment for landfill leachate depends on the waste characteristics, the extent of pretreatment and required effluent quality. The highest concentration of solute in the leachate stream for treatment on a continuous basis should not exceed 10,000 mg/L TOC which is now considered as the upper limit for the process.

Influent should not contain more 10 mg/L of oil and grease. For the removal of inorganics by activated carbon, TDS Concentrations should not exceed 1000 mg/L and more preferably be less than 500 mg/L.[47]

Activated carbon is not a suitable process for the removal of volatile fatty acids in leachates from young landfills. It is not effective for removal of very large organic molecules (such as humic acids) because of their tendency to block the pores[33][48].

For leachate treatment, activated carbon adsorption units are generally designed with the following parameters:[46]

- pretreatment step if the leachate contains over 50 mg/L suspended solids;
- granular size - 8x30 or 12x40 mesh
- contact time range from 18 - 36 minutes
- hydraulic loading range from 2 to 10 gpm/sq.ft.
- carbon requirements is 0.3-0.8 kg COD per kg carbon.

Activated carbon adsorption was chosen as the most practical and least expensive method of treating leachate from the Love Canal chemical dumpsite at Niagara Falls, N.Y.[47] At a cost of approximately 3.7 cents per U.S. gal., on-site treatment was considered as less expensive than other alternatives which require the leachate to be hauled off-site for disposal.

4.5.7 Treatment with Peat[49][50]

Peat moss is a partially decomposed plant material which is found in wet swampy areas. Due to the lack of oxygen, low temperatures, high acidity, low nutrient supply and water logged conditions, the vegetation has not decomposed completely.

Peat moss is a complex material consisting of lignin and cellulose as major constituents. It has a high absorbing capacity for excess water and a natural capacity for ion exchange with metals such as copper, zinc, lead and mercury. Its ability to retain metal ions is dependent on the pH of the solution.

At pH above 8.5, the peat moss itself is not stable. At low pH, below 3.0, most of the metals can be leached from peat moss. Between these two values, peat moss can adsorb most metals very efficiently with a capacity of up to 4 percent of its dry weight.

Table 9: Removal Potential of Activated Carbon for Inorganic Constituents

Constituent	Sorption Potential	Potential for Removal by Activated Carbon
Antimony	Very Good	Highly sorbable in some solutions
Arsenic	Very Good	Good removal in higher oxidation states
Barium	Poor	Very low
Beryllium	Unknown	Unknown
Cadmium	Poor	Slight
Chromium	Very Good	Good, easily reduces
Cobalt	Good	Trace amounts readily sorbed
Copper	Poor	Slight unless complexed
Iron	Fair	Ferric, good, ferrous, poor
Lead	Fair	Good
Manganese	Unknown	Perhaps as MnO_4
Mercury	Good	Metal can be filtered; organic forms
Molybdenum	Poor	Slight at pH 6 to 8; good if complexed
Nickel	Fair	Fair
Selenium	Poor	Slight
Silver	Poor	Reduced on carbon surface
Tin	Good	Very high
Titanium	Fair/Good	Good
Tungsten	Poor	Slight
Zinc	Poor	Slight
Phosphate		Not sorbed but may precipitate
Chlorine/Bromine		Strongly sorbed and reduced
Chloride/Bromide		Not appreciably sorbed

Adapted from: R.L. Culp, G.M. Wesner and G.L. Culp. Handbook of Advanced Wastewater Treatment. Third Ed. Harper & Roe Publishers, Inc. New York, N.Y. 1978.

Several researchers have conducted tests to investigate the applicability of peat moss for the treatment of landfill leachate. In 1978, Cameron[50] performed laboratory tests with a plexiglass column packed with peat moss in which the leachate was allowed to percolate through with a contact time of 2.9 hours. He found that the BOD_5 and COD were reduced by 25 to 75 percent. Other researchers[51] such as Rock and later McLellan and Rock at the University of Sherbrooke, found that Cd, Cr, Cu and Pb could be removed with an efficiency over 90 percent for a contact time of 24 hours.

Peat moss has been suggested for use in landfills where the leachate could be collected in peripheral ditches, impounded and allowed to percolate or flow through a dike constructed of peat moss. A careful hydraulic analysis would be required to ensure that no flooding would occur.[51]

After the peat moss has been in use as an absorbent, it would need to be stored where rainfall could not leach out and release the absorbed contaminants.

4.5.8 Chemical Oxidation

Chemical oxidation is a tertiary treatment process employed in wastewater treatment to oxidize some of the organic contaminants by the use of chemicals such as hydrogen peroxide, ozone, potassium permanganate and chlorine. The purpose of pretreatment is to remove or destroy toxic or inhibitory organics or alternatively to convert them into more readily biodegradable intermediate products which can be more easily treated by conventional biological methods.

In general, chemical oxidation methods are slightly more effective than chemical precipitation and coagulation, and their removal efficiencies have been very cost effective for reducing COD in leachates.[52]

a) Changes through Chemical Oxidation

$Fe^{2+} \rightarrow Fe^{3+}$	(forms a rust coloured precipitate)
$C \rightarrow CO_2$	(some refractory organic carbon will remain unchanged)
$NH_3 \rightarrow (NO_3)^{-1}$	(requires favourable conditions otherwise will not occur)
$S^{-2} \rightarrow (SO_4)^{-2}$	

b) Removal of Ammonia (by aeration)

Dissolved ammonia can be found in two forms in the leachate depending upon the pH:

High pH - Free Ammonia gas
Low pH - Ammonium - ion

The relative proportions of each form are controlled by pH and temperature. At high pH, the free ammonia is present likely in the gaseous form and some of this free ammonia could escape from the solution and be given off to the atmosphere. By increasing the contact between the leachate and air by bubbling the air through the leachate, removal of free ammonia is enhanced.

In actual practice, the treatment process generally consists of pH adjustment in the leachate to 11 by addition of caustic soda and then aerating to remove the free ammonia.

c) Removal of Sulphide

Hydrogen sulphide in leachate can be treated by hydrogen peroxide. Although it is not considered as a cost effective method of reducing BOD_5 to acceptable limits, the use of hydrogen peroxide is very effective in controlling odour problems associated with hydrogen sulphide.

Sulphide is converted either to sulphur or to sulphate depending on the pH:

- at pH below 8:

$$S^{-2} + H_2O_2 \rightarrow S$$

- at pH above 10:

$$S^{-2} + H_2O_2 \rightarrow (SO_4)^{-2}$$

The oxidation process is more rapid at the higher pH but any advantage from this would be more than offset by the larger dose of hydrogen peroxide required to react with a given quantity of sulphide. In addition, there is also a need to add alkali to raise the pH. In practice, a dose ratio of 3 parts of hydrogen peroxide (100 percent solution) per part of soluble sulphide has been reported to be sufficient.

In the United Kingdom, hydrogen peroxide is applied wherever the presence of sulphide in the leachate is anticipated to cause problems in the sewers. The water authorities have set a low limit on sulphide levels because of their potential hazards to sewer workers[9].

Three methods of application are used for dosing peroxide:

1) drip feed into any channel carrying leachate at a point of turbulent flow to facilitate mixing;

2) drip feed on the upwind side of a lagoon. This allows the hydrogen peroxide to spread across the surface of the lagoon. This allows the surface layer to seal the sulphide at lower layers of the lagoon;

3) spraying for large treatment applications: hydrogen peroxide is brought to the site in bulk containers or drums. It is injected into the suction pipe of the pump and applied to the leachate by a spray system.

d) Breakpoint Chlorination

Break-point chlorination is another technique which can be used to oxidize nitrogen compounds into chloramines and eventually into nitrogen. However, this method is not considered very practical because of the high chemical costs and formation of complex organic nitrogen compounds which may be toxic to aquatic life.

4.6 Biological Treatment Processes[53]

Biological treatment processes play a vital role in the management and disposal of landfill leachates. In designing an effective treatment, leachates should be considered similar to municipal sewage containing industrial wastewaters. Leachate usually contains higher levels of organic matter, total ammonia-nitrogen along with a wide range of industrial pollutants and heavy metals.

Biological treatment systems can be divided into either aerobic or anaerobic processes.

4.6.1 Aerobic Biological Treatment[53]

Aerobic biological treatment involves the biodegradation of organic matter in the leachate by the action of microorganisms in the presence of oxygen.

Aerobic biological treatment is one of the most cost-effective methods for reducing the levels of organic contaminants and ammonia in leachates.

The four phases of degradation are:

a) removal of high molecular weight humic carbohydrate organics - by adsorption on bacterial floc with a decrease in leachate turbidity;

b) decrease of free volatile fatty acids, oxidation-reduction potential and conductivity;

c) substrate removal of high molecular weight carbohydrate excreted by bacteria resulting in further adsorption on bacterial floc;

d) removal of high molecular weight organics; leachate from recently filled landfill sites contains large amounts of fatty acids that are amendable to biological treatment.

There are five aerobic biological processes for the treatment of leachate presented in this report. These are:

a) activated sludge;
b) co-disposal at municipal sewage treatment plants (STPs);
c) rotating biological contactors;
d) trickling filters;
e) aerated lagoons.

4.6.1.1 Activated Sludge

The activated sludge process involves the use of aerobic micro-organisms for the biodegradation of organic matter. The leachate is mixed with recirculated sludge biomass and aerated in an open tank by diffuse or mechanical aerators. This action provides oxygen to the aerobic bacteria to metabolize and biodegrade the organic matter in the leachate. The biomass is settled out as a sludge and is then remixed with the incoming leachate.

There is an upper limit of 10,000 mg/L of BOD_5 as organics in the wastewater/leachate feed to the activated sludge process[36]. In addition, an activated sludge treatment system is very sensitive to rapid changes in organic loading, chemical quality and flow conditions. It has been suggested that an activated sludge system for leachate should be preceded by equalization to buffer sudden changes in hydraulic and organic loadings; chemical precipitation and sedimentation to remove metals (if calcination is a problem) and suspended solids; neutralization to a neutral pH and nutrient addition to maintain proper levels of phosphorus and sometime nitrogen. In addition, post treatment with activated carbon may be required for leachates with high COD levels or high non-biodegradable content.

4.6.1.2 Co-disposal at Municipal Sewage Plants

One method of treating leachate is co-disposal with municipal sewage at a local sewage treatment plant. The leachate can be mixed with the sewage by either being discharged into a sewer system or transported directly to the sewage plant.

The impact of the shock loading on the plant operation could be critical if the strength of the leachate was significantly higher than that of the influent sewage. In rare occasions, the leachate flow can be a significant portion of the total flow when the leachate is added as a batch flow.

A recent survey by the Ontario Ministry of Environment and Energy (MOEE) [54] has shown that leachates are co-disposed at 31 sewage plants in Ontario. Some 614,000 m^3 are discharged annually to the sewage plants without leachate pretreatment. This represented a flow-range from 0.009 to 0.8 percent of the total plant flow with an average of 0.2 percent.

A study conducted by Pollutech Limited[55] has indicated that two Burlington (Ontario) municipal sewage plants receiving leachate and industrial wastes are capable of accepting higher leachate flows and could handle leachate flow up to 2.5 percent of the total volumetric flow to each plant. The Pollutech study recommended that certain operational processing such as aeration and sludge handling, may require upgrading to maintain effluent quality.

A bench-scale leachate treatability study [56][57] was conducted by the Regional Municipality of Waterloo to investigate the potential impacts of landfill leachate on the operation of the Waterloo sewage treatment plant and the impact on effluent quality. The leachate had BOD_5 values in range of 27,000 to 36,500 mg/L, COD values in the range of 6,000 to well over 66,000 mg/L and free ammonia in the range of 900 to 1,550 mg/L Total NH_3-N. The results showed that leachate up to 2 percent of flow by volume could be treated without any adverse effects on the effluent quality. However, the sludge production increased by 10 percent and 19 percent respectively when the leachate dosages increased from 1 percent to 2 percent. As a result, the Waterloo sewage treatment plant was expanded in 1988 to accommodate the co-disposal of landfill leachate.

Boyle and Ham[32] found that landfill leachate with a strength of up to 10,000 mg/L COD can be added to domestic sewage in an extended aeration activated sludge plant up to a level of 5 percent by volume without seriously affecting the effluent quality. Any additions beyond 5 percent by volume, resulted in substantial increases in sludge, increased oxygen uptake rates and poor sludge settling.

A Swedish study[58] of treating equalized leachate from 100 landfills indicated two problems resulting from co-disposal. One is upsets to the biological treatment processes due to high ammonia concentrations in the leachate. The second one is where low temperatures in the leachate create ice formation on the treatment equipment and also affect the biological processes. This may result in less than satisfactory treatment of the leachate.

In West Germany[59], the leachates are co-treated with sewage without any difficulties in a well designed sewage plant. Ehrig stated that BOD_5 and nitrogen concentrations can be reduced to low levels in the effluent.

Elimination of ammonia is considered an important process at many activated plants in West Germany, especially for leachates from old landfills.

The results of a pilot study conducted by U.S. EPA[60] at Cincinnati (Ohio) concluded that the landfill leachate could be mixed with domestic sewage and treated at a municipal sewage treatment plant with a secondary activated sludge process. However, the plant must comply with the following conditions:

a) sufficient aeration capacity to accommodate increased organic loadings;

b) absence of toxic substances (at toxic levels) in the leachate;

c) facilities available to add phosphorus if needed.

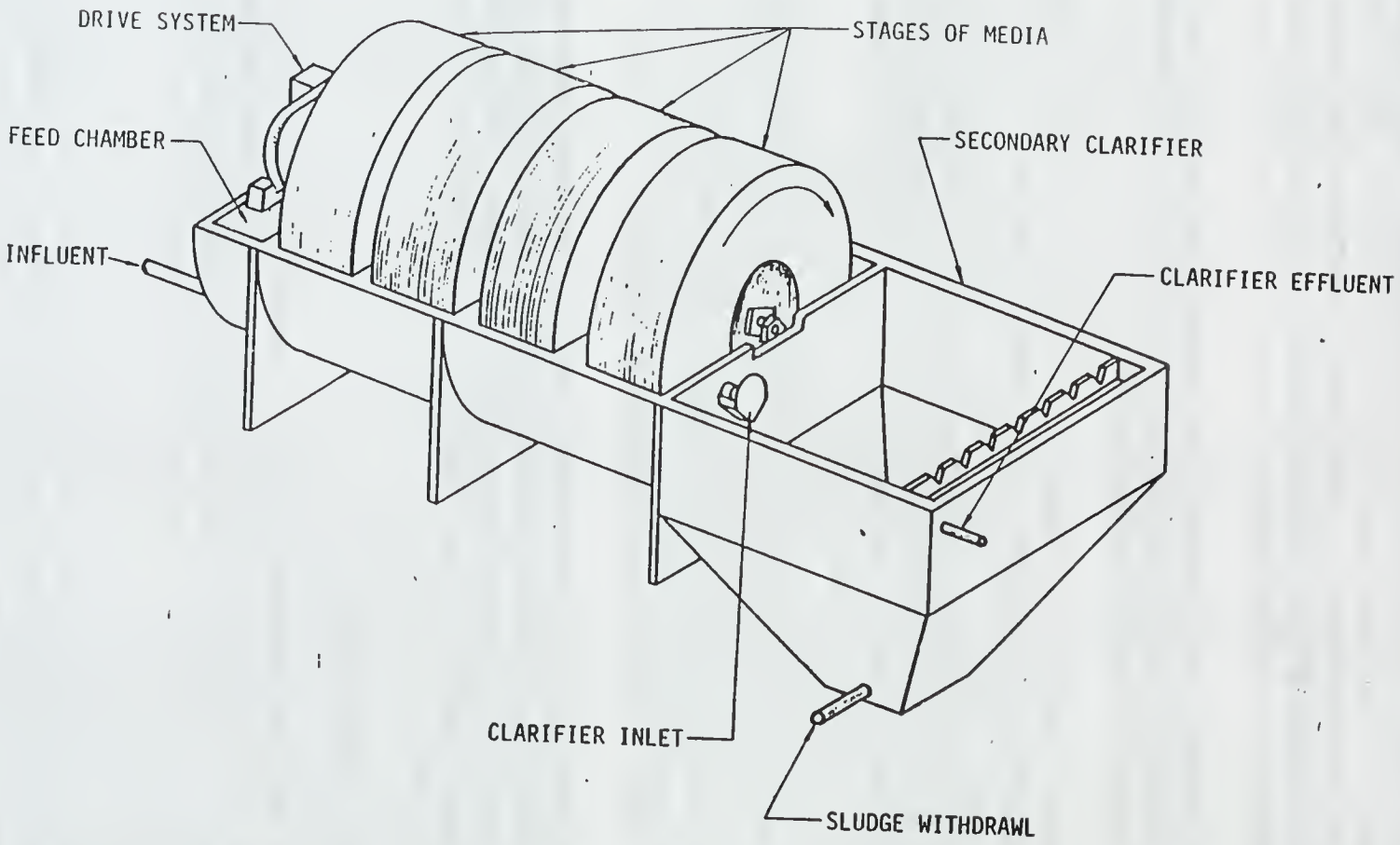
Any problems that can be expected in the co-treatment of municipal sewage and landfill leachate are said to be no different from those experienced in treating any high strength organic wastes which are deficient in nutrients. However, restricting the addition of leachate to off-peak loading hours would eliminate the need to increase aeration capacity.

4.6.1.3 Rotating Biological Contactor

The rotating biological contactor (RBC) was commercialized during the early 1960's in West Germany for use in the secondary treatment of municipal and industrial wastewaters. During the mid-1980's the U.S. Environmental Protection Agency (USEPA) began to test the effectiveness of RBC in treating leachates from hazardous waste sites[61].

The rotating biological contactor (RBC) process, as illustrated in Figure 7, consists of a series of closely spaced light weight plastic discs mounted on a horizontal shaft supported in a semi-circular or trapezoidal tank. Each disc measures 1.84m (6 ft.) to 3.68m (12 ft.) in diameter. The disc assembly is near one third immersed in the leachate flow and rotated slowly.

Figure 7: Details of a Rotating Biological Contactor



Source: Biological Treatment of Food Processsing Wastewater; Design and Operations Manual. Environment Canada Economic and Technical Review Report, October 1979. EPS 3-WP-79-7.

At the start of the process, micro-organisms, which are naturally present in the leachate or that were seeded from other sources, begin to attach themselves to the discs, they multiply and cover the entire surface of the discs. As the discs are rotated, the discs carry a film of leachate above the liquid surface where it absorbs oxygen from the air. The process maintains aerobic conditions in the leachate and the micro-organism layer.

As the microbial growth continues, the biological film on the surface of the disc becomes heavier and portions eventually fall off (known as sloughing) due to gravity and shear force generated by the rotating action. This sludge is removed from the treated leachate by settling.

Originally, the rotating biological contactor (RBC) was developed as an aerobic treatment process but can also be operated as an anaerobic process. The anaerobic RBC process has the ability to take advantage of the fixed film, horizontal flow capabilities of an RBC process with the potential of degrading high strength carbonaceous wastes.

A review of the technical literature indicates that the RBC process is amenable to wastes with soluble BOD_5 and high ammonia levels. Early studies took place at a municipal landfill site at St. Julie (Quebec) during 1981[62]. The study showed high ammonia levels in the treated effluent.

As a result of their pilot scale study over a 21 month period, Peddie and Atwater[63] reported that an efficient treatment of leachate could be maintained with RBC even under difficult operating conditions. The RBC was found to be very resistant to variations and interruptions in organic and hydraulic loadings. At one point, even with a four fold increase in the organic loading over a four day period, the RBC produced a good quality effluent with a slight increase in BOD_5. Typical capital and operating costs for sizes of installations are given in Table 10.

More recently, there has been a pilot demonstration study[64] completed by the Regional Municipality of Peel to evaluate the performance on the RBC unit for the treatment of leachate from a municipal landfill site. Data indicate that the RBC treatment was capable of reducing the leachate COD levels from well over 19,000 mg/L by at least 90%.

As a result of this study, the municipality has constructed a leachate treatment facility with RBC equipment capable of handling 40 m^3 flow rate with 135 kg/day BOD_5.[65]

The plant consists of two RBC units with 5,900 m^2 of surface area. The plant has a chemical flocculation system to improve effluent clarity. Vacuum filtration is available for sludge dewatering. The effluent is discharged into the municipal sewer system. The facility began its operation in December, 1991.

TABLE 10: Capital and Operating Costs for Rotating Biological Contactor

Capacity (litres/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
CAPITAL COSTS ($)			
RBC Unit	$100,000	$135,000	$175,000
Total Equipment Costs	$100,000	$135,000	$175,000
Installation Costs	$160,000	$216,000	$280,000
TOTAL CAPITAL COST	$260,000	$351,000	$455,000
OPERATING COSTS ($/YR)			
Labour 1.5;2;2.5hr/day@$45/hr	$24,638	$32,850	$41,063
Maintenance	$10,000	$13,500	$17,500
YEARLY OPERATING COSTS	$34,638	$46,350	$58,563
TOTAL COSTS ($/yr)			
Amortized Capital Costs 10yr @ 11%	$44,200	$58,670	$77,350
Operating Costs ($/yr)	$34,638	$46,350	$58,563
TOTAL YEARLY COSTS	$78,838	$106,020	$135,913
Cost per 1,000 litres	$3.93	$2.64	$2.26

Sources: Field Demonstration of Membrane Technology for Treatment of Landfill Leachate. Environment Ontario, RAC Project No. 439c, December 1991.

At the present time[65], the flow rate of the leachate is 19 to 20 m^3 per day with a concentration of 110 to 450 mg/L BOD_5 and 600 mg/L to 1100 mg/L COD. The BOD_5 is reduced by up to 90% and COD by 55%. The sludge dewatering has not yet been needed due to the underloading of the system.

Advantages of the RBC include:

a) tolerant of shock loadings and fluctuating flows;
b) low capital costs;
c) no foaming problems;
d) lower space requirements;
e) lower operating and maintenance costs.

Disadvantages include:

a) high metal content may be toxic to micro-organisms and adversely affect performance;
b) low temperature ambient air may adversely affect performance (heater may be required for winter operation);
c) suspended solids may plug up the discs;
d) system may go anaerobic and create odour problems.

4.6.1.4 Lagoons[53]

Treatment or storage of landfill leachate can be achieved in lagoons or waste stabilization ponds. These are usually large shallow basins or earthen pits which have been excavated or constructed in an area close to the landfill site. They are usually lined with impermeable materials to prevent seepage or migration of the leachate from the impoundment area.

The stabilization or oxidation of the organic constituents in the leachate results from the biological activity of various micro-organisms which live in the lagoon under aerobic conditions.

Three types of lagoons are available for leachate treatment depending on the design features and microbial activity:

a) aerobic (with oxygen present);
b) anaerobic (with the absence of oxygen);
c) facultative, i.e. combination of (a) and (b).

The anaerobic and facultative lagoons are discussed in the Anaerobic Biological Treatment Section (4.6.2) of this report.

Aerobic lagoons are usually very shallow basins that are used for treatment of wastewater by the action of algae and bacteria. These micro-organisms are found in suspension and aerobic conditions prevail throughout the entire lagoon.

There are two types of aerobic stabilization ponds or lagoons. The first type depends on the symbiotic relationship of algae and bacteria. Aerobic conditions are maintained by algae growth through photosynthesis and by surface oxygenation. Oxygen is produced by algae through the action of photosynthesis and in turn, consumed by the bacteria during the aerobic degradation of organic matter in the leachate. The success of these aerobic ponds depend on the prolific growth of algae. These ponds are usually very shallow (approximately 15 to 45 cm).

In the second type of aerobic stabilization lagoon, air is artificially introduced into the liquid by means of mechanical surface aerators. There are other aerated lagoons where air is introduced at the bottom through perforated air hoses or diffused aerators. Usually these lagoons are much deeper, up to 3 m.

In general, aerated lagoons can only treat low strength leachate and therefore are best suited as a polishing step used in conjunction with other treatment.

Recommended loadings for aerated lagoons are less than 0.05 kg $BOD_5/m^3/d$ and results in 0.5 kg sludge per kg BOD_5 removed. Other design details are in Table 11.

4.6.2 Anaerobic Biological Treatment[66][67][68]

Anaerobic biological systems involve micro-organisms to convert organic matter in the leachate into methane gas in the absence of oxygen.

The potential of the anaerobic biological process was not fully realized for long time due to a lack of understanding of the microbiological and biochemical fundamentals of anaerobic digestion process[61]. The anaerobic process has now been demonstrated by several research workers to be effective in reducing organic loadings from landfill leachates.[67]

Anaerobic treatment of leachate occurs in four stages[66][67][68] as shown in Figure 8:

a) hydrolysis: non-soluble organic compounds in the leachate are hydrolysed or degraded by enzymes or fermentative bacteria. Since the rate of this process is slow, it is often regarded as the rate-controlling step for the anaerobic treatment process;

b) acid formation: the hydrolysed compounds from (a) are converted by acid-forming bacteria into organic acids such as lactic acid, butyric acid, propionic acid and acetic acid as well as into alcohol, hydrogen, carbon-dioxide and soluble organics;

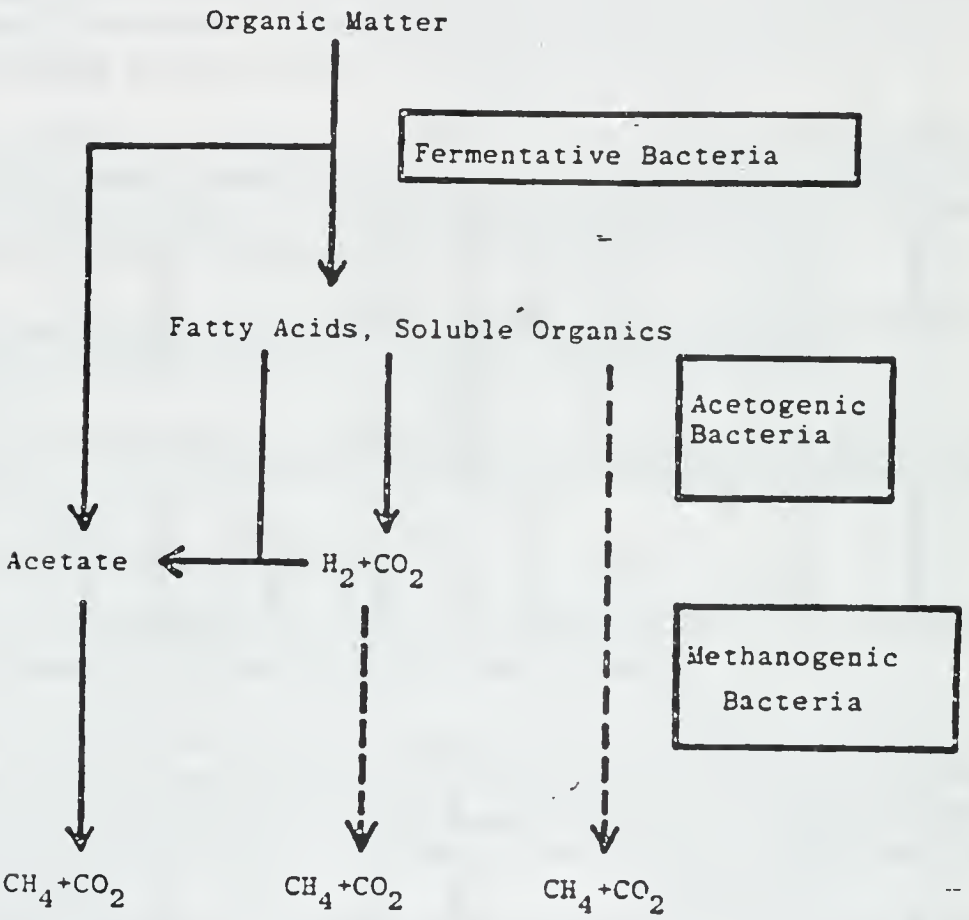
TABLE 11: Design Criteria for Waste Stabilization Ponds

	Aerobic	Facultative	Anaerobic	Aerated
Depth (m)	0.274 to 0.549	0.549 to 1.37	2.29 to 5.49	0.91 - 5.49
Organic Loading (kg BOD_5/ha/day)	100.1 - 200.2	10.01 to 100.1	200.2 to 2002	10.01-300.3
Detention Time (days)	2 to 6	7 to 30	30 to 50	3 to 10
Influent BOD_5 (mg/L)	200	200 to 500	500 and up	200 to 500
Flow Regime	Intermittently mixed	Mixed surface layer	Not mixed	Completely mixed
Principal Conversion Products	Algae, CO_2, bacteria	Algae, CO_2, CH_4, bacteria	CO_2, CH_4, bacteria	CO_2, bacteria
Algae Concentration (mg/L)	40 to 100	10 to 80	0 to 5	--
Operating pH	6.5 to 10.5	6.5 to 9.0	6.8 to 7.1	6.5 to 8.0
Effluent Suspended Solids	10 to 140	40 to 100	80 to 160	80 to 250

Adapted from: Metcalf and Eddy, Inc. Wastewater Engineering, 1979.

FIGURE 8

Anaerobic Conversion of Organic Matter to Methane



Source: Obayashi, A.W. and J.M. Gorgan. Management of Industrial Pollutants by Anaerobic Processes (p.2). In: INDUSTRIAL WASTE MANAGEMENT SERIES. Edited by James W. Patterson, 1985.

c) acetogenesis: organic acids from (b) are converted into acetic acids, hydrogen and carbon-dioxide;

d) methanogenesis: the organic acids from (b) and (c) are converted into methane gas by methanogens or methane forming bacteria. Some researchers consider this to be a rate limiting process due to the environmental conditions and slow growth activity of the methane-formers.

Two factors which influence the rate limiting step in the anaerobic process, conversion of organics into methane gas, are:

a) at high retention time of solids (greater than 10 days) the rate of hydrolysis for organic solids is very slow;

b) the growth rate of fermentative or acid formers is faster than that of the methanogens. With the production of organic acids, there is a tendency for the pH to drop and the activity of the methanogens is inhibited by the lower pH.

The anaerobic process for the treatment of landfill leachate offers several important advantages over the aerobic treatment process.

Advantages of anaerobic treatment include:

a) low production of sludge;
b) production of sludge with better dewatering characteristics;
c) low nutrient requirements;
d) no aeration equipment required;
e) useful end product - methane;
f) sludge can be preserved without any feed for a period of a year or more with no serious deterioration;
g) less sensitive to toxic compounds than aerobic process.

Disadvantages include:

a) the process is subject to upset and difficult to control;
b) start-up of the process using sewage sludge may take a period of 8 - 12 weeks;
c) process requires long retention times.

4.6.2.1 Anaerobic Lagoons[68]

Anaerobic lagoons are ponds in which the decomposition or stabilization of organic components in the leachate takes place as a result of microbial activity under low or no oxygen levels. In contrast to aerobic lagoons, anaerobic systems are deeper and require much less surface area. They have the ability to handle much higher organic loads.

Sludge build-up in anaerobic lagoons is much less than for aerobic; for each kg of BOD_5 destroyed by the anaerobic process, only about 0.1 kg of sludge is produced as compared with 0.5 kg for an aerobic system. Typical design details are in Table 11.

The major disadvantage of an anaerobic lagoon is that it can produce strong odours unless the sulphate level in the leachate is maintained well below 100 mg/L.

Obnoxious odours from anaerobic leachate lagoons or storage tanks can be controlled or suppressed by raising the leachate pH to about 10. This can be done by adding lime or caustic soda to convert the dissolved hydrogen sulphide to sulphide ions. Operating pH in the lagoons should be maintained near 7 however, once odours are under control.

Other oxidizing chemicals such as calcium hypochlorite and sodium hypochlorite can also be used for this purpose.

4.6.2.2 Other Anaerobic Processes

Because of the slow growth of methane-forming bacteria, relatively long detention times have been required for the conventional anaerobic process to stabilize the organic materials in the leachate. Different anaerobic treatment processes have been developed to overcome this problem and provide more suitable conditions for the methanogens.

The anaerobic processes described below include:

a) upflow filter;
b) sludge blanket.

Anaerobic Upflow Filter[66][67][68]

The principle of an anaerobic upflow filter is to retain the biological growth on a support medium or packing material.

The system consists of an upflow reactor which contains a rock media or plastic media. The liquid is uniformly distributed and allowed to flow upward through the filter media. The biological solids develop as a film on the media surface or become trapped in the voids between the media. The packed filter media, by retaining the biological solids, prevents solids from floating off into the effluent (see Figure 9) and so the anaerobic solids are retained in the system allowing the methanogens to develop.

Since the anaerobic process requires longer solids retention times to accommodate the slow growth of methanogens, the development of the anaerobic upflow filter represents a significant advancement in the use of anaerobic treatment for treatment of low strength waste at high flows.

This anaerobic process was selected[69] for the treatment of landfill leachate at the Highway 101 Landfill serving the City of Halifax and to surrounding area municipalities. This was selected after 3 years of extensive laboratory and pilot studies.

The leachate treatment system consists of two anaerobic reactors capable of handling up to 9 kg COD/m^3/d. These are operated at 35°C to generate methane. The influent BOD_5 is in order of 24,000 mg/L and COD of 15,000 mg/L. The treatment is reported to remove over 95% of the BOD_5 and COD. The treated effluent is discharged into an aerated lagoon for further treatment before discharge into the Sackville River. The effluent COD is said to average 114 mg/L while the BOD_5 was at 2 mg/L.

Upflow Anaerobic Sludge Blanket[66][68][70][91][92]

The upflow anaerobic sludge blanket (UASB) process was developed during the early 1970's in Holland and replaces the support medium noted above with a floating sludge blanket (see Figure 10).

The leachate enters evenly across at the bottom of the reactor and flows upwards through the sludge bed. The organic matter in the leachate is consumed by the microbial population in the sludge bed and converted into biomass and gas.

Above the bed is the sludge blanket zone which provides an area for an ideal mixing between the organics in the leachate and the micro-organisms.

Throughout the biological activity, gas production results in the formation of gas bubbles. As the gas bubbles rise through the sludge blanket, they provide gentle mixing.

Figure 9: Anaerobic Upflow Filter

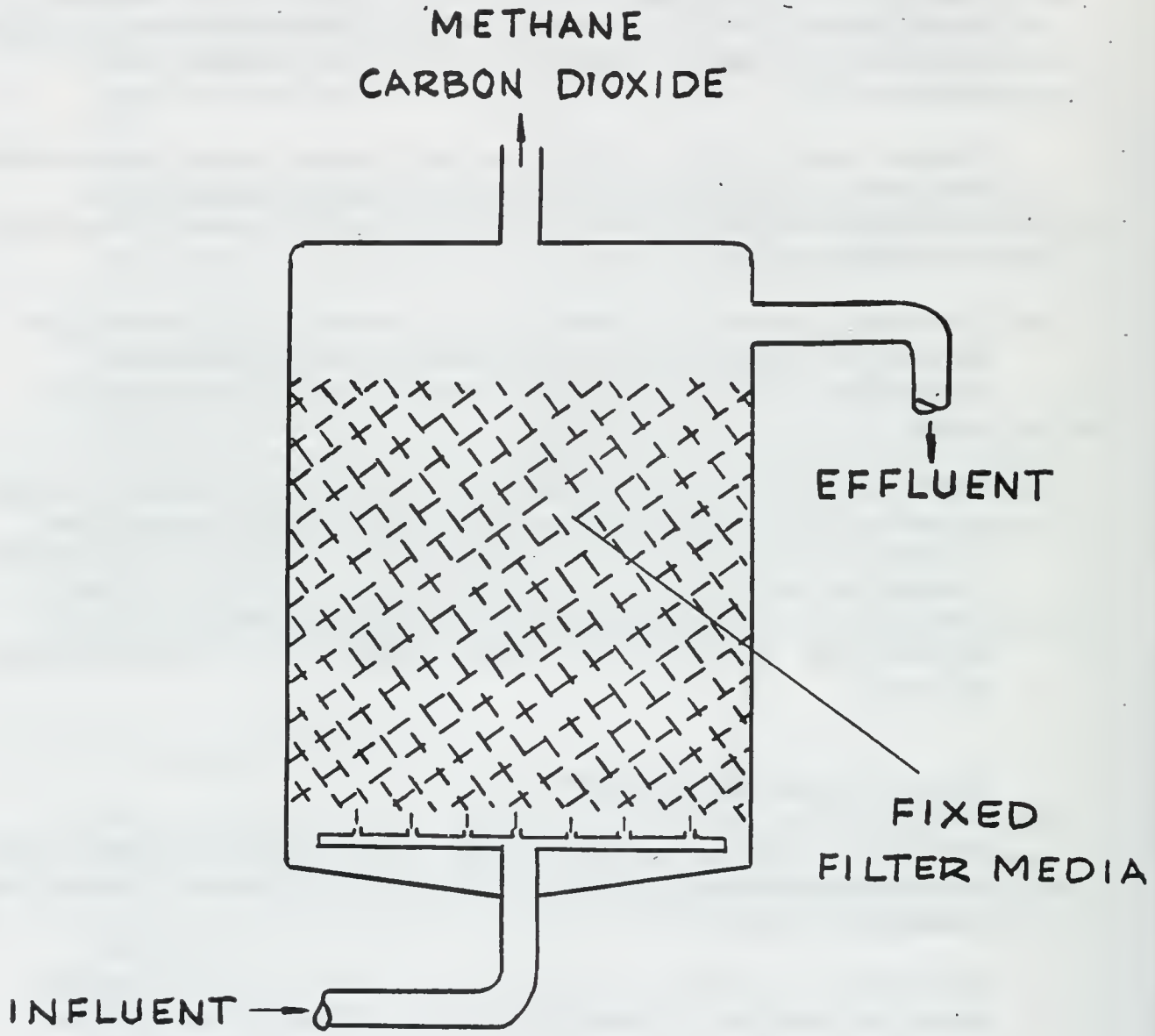
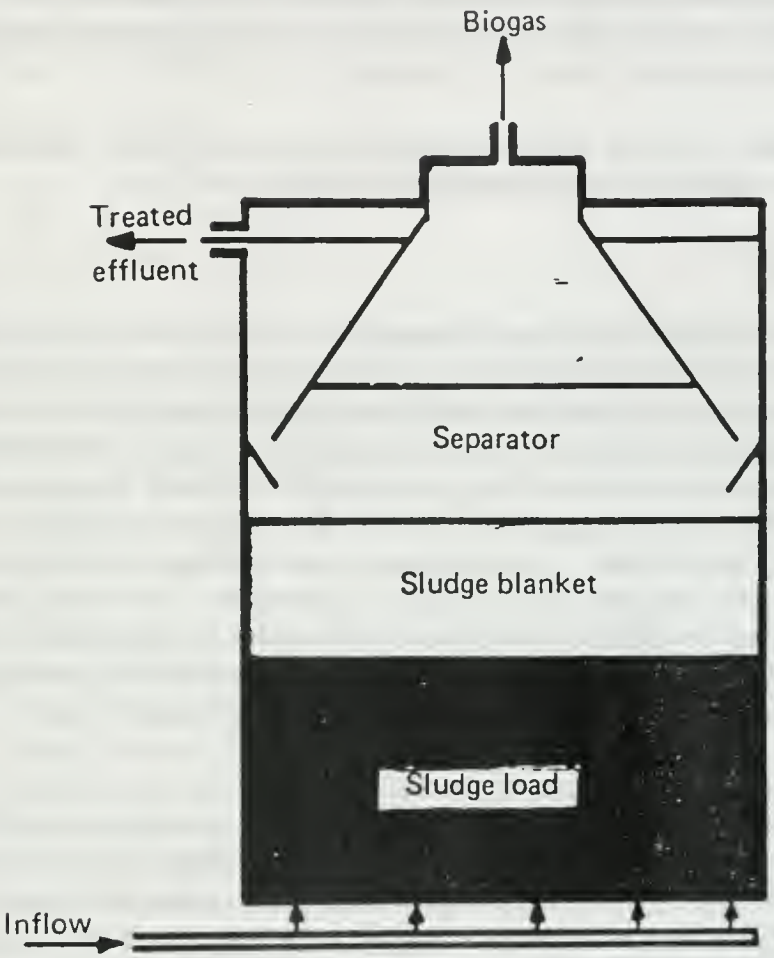


Figure 10: Main Components of a UASB Reactor



Source: Torpy, M.F. Anaerobic treatment of industrial wastewaters. Poll. Tech. Rev. No. 154., Noyes Data Corporation, Park Ridge, NJ, 1988.

b) low temperatures: biological processes are highly dependent on temperature. Process efficiency could be significantly reduced if the temperatures fall below 35°C for anaerobic digesters and 10°C for anaerobic filters. Other researchers state that long sludge retention times could compensate for the performance at lower temperatures by increasing the biomass concentration;

c) ammonia: under anaerobic conditions, the organic nitrogen in the leachate is converted into ammonia or ammonium nitrogen. This is considered undesirable as it may lead to problems of ammonia toxicity and eutrophication in the receiving water;

d) heavy metals: very low concentrations of copper, nickel, zinc and hexavalent chromium can be toxic if present in soluble form.

4.7 Nitrogen Removal[72][73]

One of the prime objectives of leachate treatment is to remove nitrogen, particularly when it is in the form of ammonia or ammonium nitrogen. The levels of total ammonia nitrogen commonly found in landfill leachates (especially "older" leachates) are much higher than those typically found in municipal sewage. This results from the breakdown of proteinaceous materials in the landfilled wastes during the anaerobic process in which the organic nitrogen is converted into ammonia. In many cases, high concentrations of ammonia, especially those over 800 mg/L, could become a serious water pollution problem. Free ammonia is relatively toxic to fish and other forms of aquatic life. In addition, nitrification at the receiver point causes a high demand for dissolved oxygen. Therefore, it is imperative to reduce the levels of ammonia before the leachate is discharged to any receiving stream.

The presence of high concentrations in the leachate, generally over 100 mg/l ammonia, is sufficient to inhibit microbial activity and therefore interfere with biological processes. Knox[72] noted that most leachates stabilized by recirculation through the landfill were usually much weaker in organic content but they may contain high concentrations of ammonia. Leachates from old landfills would also have high ammonia concentrations.

Biologically, ammonia can be oxidized to nitrate (nitrification). This is a two-step process with nitrite as an intermediate product:

a) first step:

$$NH_4^+ + 1.5\ O_2 \xrightarrow{\text{Nitrosomonas bacteria}} NO_2^- + H_2O + 2H^+$$

b) second step:

$$NO_2^- + O \xrightarrow{\text{Nitrobacter bacteria}} NO_3^-$$

Another by-product of this reaction is the formation of a hydrogen ion which reacts with the bicarbonate in the water:

$$H^+ + HCO_3^- \rightarrow H_2CO_3$$

This results in a lower pH which, in turn, can inhibit nitrification. In leachate treatment, the oxygen required for nitrification is 4.6 mg O_2 per mg N oxidized. Without a sufficient level of dissolved oxygen, nitrification would fail. Both groups of bacteria participating in the above nitrification reactions have low growth rates and can be inhibited by environmental conditions such as:

a) low pH;
b) insufficient dissolved oxygen (less than 2 mg/L);
c) low temperatures;
d) toxic chemicals.

In his investigations of various options, Knox[72] felt that removal of ammonia in leachate could be best achieved by physical/chemical treatment involving air stripping or by biological methods. Air stripping was reported to be a viable method either as a pretreatment for biological process or as a main treatment where it was not necessary to attain a high percentage reduction of ammonia [73]. To achieve a high percentage removal with a high effluent quality, biological treatment was thought to be a better option.

To assess the possible treatment efficiency and develop design data for a full-scale biological treatment plant, Knox conducted a two-year on-site study at the Pitsea (England) landfill using activated sludge and biological (trickling) filter pilot plants to treat stabilized leachate[73].

He found that the activated sludge treatment yielded good ammonia removal but poor solids clarification and BOD_5 removals. This was attributed partly to the low BOD_5:NH_3-N ratio. He indicated that the effluent from the biological treatment was clear with a slightly lower level of BOD_5, but the ammonia levels in the effluent were slightly higher. He stated this was due to the biological filter being an attached growth process in contrast to a suspended growth process in the activated sludge plant. There were a number of operating problems associated with the activated sludge plant. These included:

a) foaming;
b) temperature variations in the leachate;
c) scaling, clogging and corrosion;
d) nutrient deficiencies;
e) influent quality;
f) loss of sludge.

Because of these problems, he felt that biological treatment with an attached growth process such as the one available with biological filters and rotating biological contactors (RBC) give better treatment results.

Eventually for a full scale treatment plant, a RBC process was chosen over an activated sludge process. The biological filter was eliminated because of its high capital and operating costs. Operating costs for the RBC were much lower than the activated sludge plant because of the lower power requirements. Overall, the RBC plant would likely have fewer operational problems and less daily maintenance.

4.8 Wetlands

During recent years, there has been a pressing need to develop innovative and cost-effective solutions to deal with leachate problems from smaller landfills located in remote areas.[74]

The use of natural biological systems such as wetlands is receiving increasing attention since a number of landfills are strategically located adjacent to natural wetlands.

Wetlands are defined as lands which are inundated or saturated with surface water or groundwater long enough each year to maintain saturated soil conditions[77][78]. These areas are usually found capable of supporting the growths of typical vegetation and aquatic life that require or are adapted to saturated soil conditions. Some of these emergent vegetation may include cattails (*Typha*), bullrushes (*Scirpus*), reeds (*Phragmites*) along with a wide variety of grasses, trees and shrubs found in the wetlands.

These shallow water or saturated areas exist as natural wetlands and are referred to in the popular usage as swamps, marsh, bogs, etc.

Wetlands have been studied extensively during the past twenty years and demonstrated successfully in Canada, Europe and the United States for wastewater treatment. Research has been conducted on natural and constructed wetland system for polishing secondary effluents and urban runoffs[72][75][76][77][78].

4.8.1 Constructed Wetlands

Constructed wetlands are defined as a designed complex of saturated substrates, emergent and submergent vegetation, animal life and water that simulate natural wetlands. Other terms include, engineered and artificial wetlands[77].

Most natural or constructed wetlands have five principal components (see Figure 12):

a) supporting beds with various rates of hydraulic conductivity;
b) plants which can thrive in water-saturated and anaerobic conditions;
c) water column (water flowing in or above the surface of the substrate);
d) animals (invertebrates and vertebrates);
e) an aerobic and anaerobic bacterial population.

4.8.1.1 Surface Flow (SF) System with Emergent Plants[74]

A surface flow (SF) system consists of basins or cells with natural or constructed clay bottom or a liner to prevent seepage. The basin is filled with soil or another suitable medium to support emergent vegetation. Water, at relatively shallow depths, flows over the soil surface.

The presence of plant stalks and debris in such basins helps to prevent short-circuiting.

4.8.1.2 Subsurface Flow System[74]

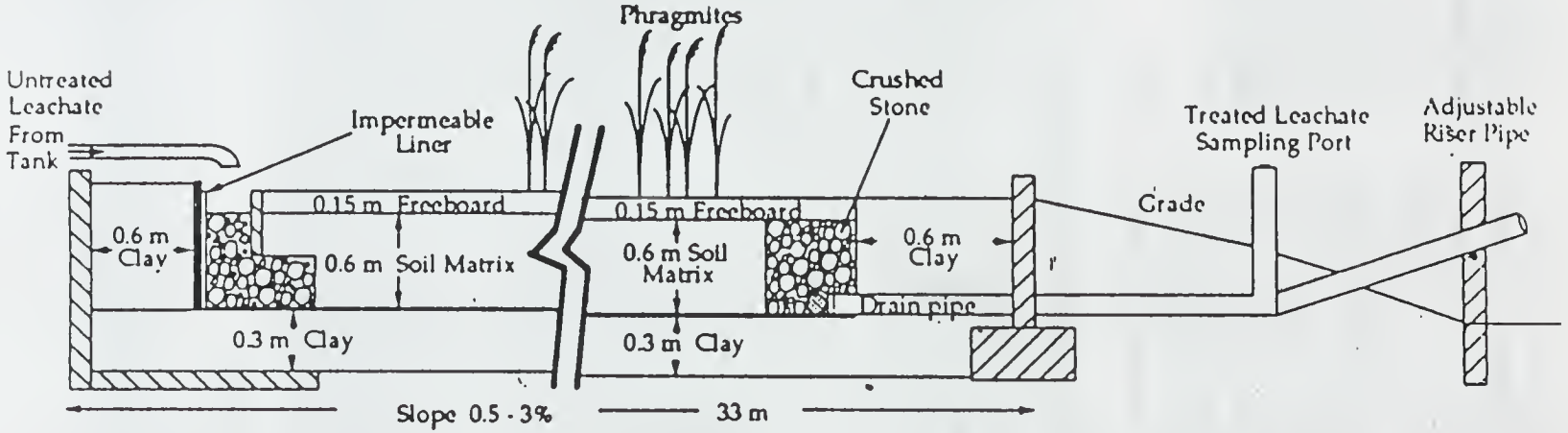
A subsurface flow (SSF) system consists of a lined trench or basin filled with gravel or rock media. Placed on top of this gravel bed is a layer of soil or another suitable medium to support a growth of emergent vegetation with an extensive root system. The system is built with a slight slope from the inlet to outlet of 0.5 to 3% (Figure 13).

The leachate flows horizontally through gravel bed into the rhizosphere (root area) of the wetland plants. During its passage through the rhizosphere, the wastewater is treated by filtration, sorption, precipitation and microbial degradation. The treated effluent is discharged to the receiving stream.

4.8.1.3 Reed Bed Treatment System

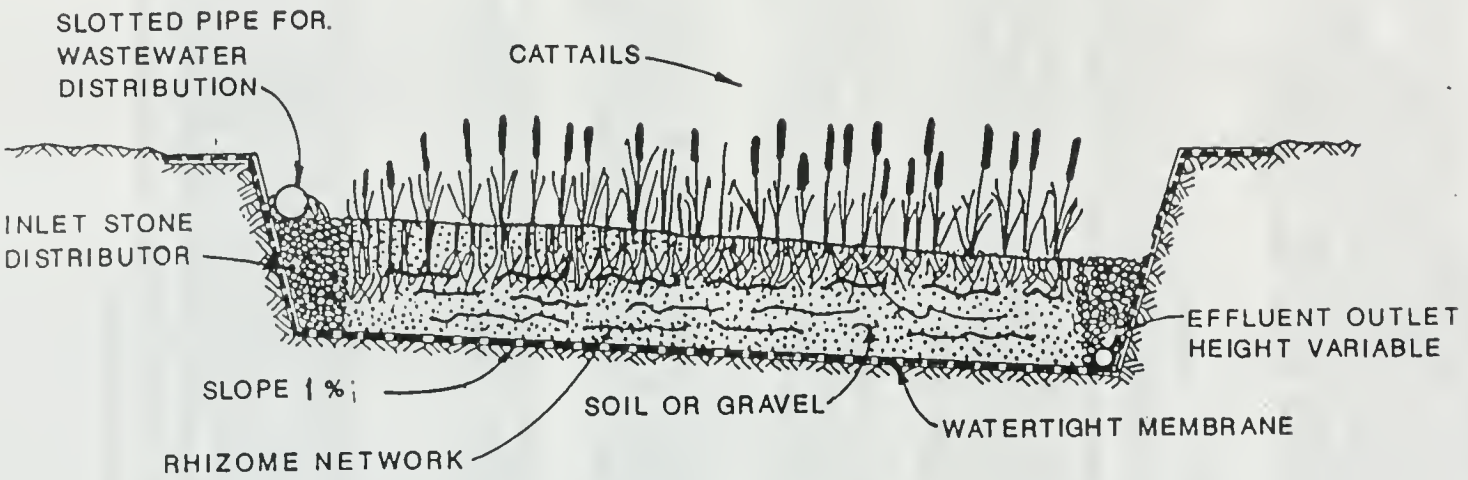
Reed bed treatment (RBT) system is modification of the SSF design. It contains reeds (*Phragmites Australis*) growing in a bed of larger sized gravel. The major difference is that the flow rate of the leachate is faster in the RBT system.

Figure 12: Schematic of a Constructed Wetland Bed



Source: Staubitz, W.W. et al. [81] Potential use of constructed wetlands to treat landfill leachate. In: Constructed Wetlands for Wastewater Treatment. Ed. D.A. Hammer. Chap.41c, pp 735-742, 1990.

Figure 13: Cross-sectional view of subsurface flow system



Source: Design Manual [74]. Constructed wetlands and aquatic plant systems for municipal wastewater treatment. U.S. EPA, Cincinnati, OH, 1988. EPA/625-1-88/022.

The key features of the systems are:[81]

a) rhizomes of reeds grow vertically and horizontally opening up the soil to provide a hydraulic pathway;
b) treatment is accomplished by bacterial activity (aerobically in the rhizosphere and anaerobically in the surrounding soil);
c) oxygen is transferred to root area by the plants;
d) suspended solids in the leachate are biodegraded in the above ground layer along with debris of dead leaves and stems.

4.8.2 Wetland Examples

Studies have been undertaken at three locations in New York State to investigate the feasibility of constructed wetland systems in full-scale landfill leachate treatment[79][80]. At Fenton in Broome County, the use of an artificially constructed wetland system was selected for an on-site treatment after a seven-month laboratory study because of its lower cost and energy requirements than the method involving transportation of leachate to a municipal sewage treatment plant.[80]

Experiments are also being conducted with constructed wetland systems in Allegany County and Tompkin County with funding provided by the New York State Energy Research and Development Agency (NYSERDA)[81]. The specific objectives of these experiments are to examine:

a) the efficiency of leachate treatment as a function of substrate material, plant growth, leachate quality and climatic conditions;
b) effects of plant growth and leachate application on hydraulic characteristics of the bed;
c) impact of leachate quality on plant growths; and
d) the physical and chemical processes by which the metals are fixed or transformed.

At Fenton,[80] the constructed wetland system, as shown in Figures 14 and 15, consists of four beds in series, each having dimensions of 3.7 m x 30 m, and lined with geomembrane and clay to prevent leachate migration to the underlying aquifer. The first two beds contain a 61 cm layer of soil vegetated with reed canary grass (*Phalaris arundinacea*). The third and fourth beds are parallel root-zone beds containing a 61 cm of course gravel with one of these planted with cattails, (*Typha sp.*) and the other remaining unplanted as a control.

The leachate is pretreated using the overland flow in the first and second beds for the removal of iron and manganese. This is followed by horizontal flow through root-zone in the bed of wetland plants.

Experiments are being conducted in Allegany and Tompkins Counties[81] on plots which are 30 m long, 3 m wide and 0.6 m deep with varying combinations of slope, substrate and planting. The plots are planted with a species of reed, (*Phragmites Australis*), native to New York State. Two plots are designed as root-zone systems, four are designed as rock-reed filter systems and two plots have gravel substrates without plants to serve as controls.

Reed bed treatment systems are in wide-spread use in the United Kingdom and various European countries for treatment of sewage effluents. There are over 100 units in each of Denmark and West Germany.

The concept of utilizing wetlands densely populated with *Typha* (cattails) has been investigated in Ontario for the treatment of municipal sewage effluents at Listowel (Ontario) [84]. During four years (1980-84), five experimental marsh treatment systems, constructed adjacent to the existing sewage works, were tested. Various designs were used, including channelled marshes, complex and simple shallow marshes, and a deep pond. The channelled marsh configuration was the most efficient design for pre-treated sewage. Levels of suspended solids, BOD_5 and total phosphorus were between secondary and tertiary treatment levels.

The results of these investigations showed that artificial wetland systems populated with *Typha augusti fola* (cattails) were effective in reducing the levels of BOD_5 and suspended solids in treated secondary effluents during the summer but the efficiency declined during winter.

Neil and Graham [85] conducted similar studies for 2 years (1986-87) at Port Perry (Ontario) with Typha along with cells containing monocultures of *Phragmites Australis* (common reed) and *Scirpus Validus* (bulrush). Four steel cells (15 m by 1.5 m) were constructed adjacent to te existing demonstration marsh and monoculture stands were established the first year in three cells, the fourth cell used as a control. Loading rate was maintained at 200 m^3/ha/day. The water depth ranged from 15 to 30 cm, with retention time ranging form 5 to 15 days. They found that Typhas was not as effective as other two emergent aquatic plants in treating domestic sewage effluent for the removal of ammonia and hydrogen sulphide.

Figure 14: Cross-section view of root zone bed

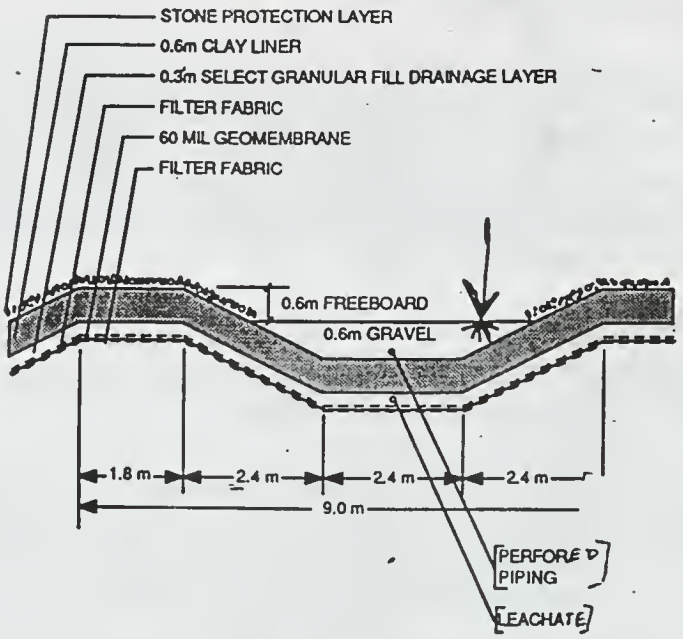
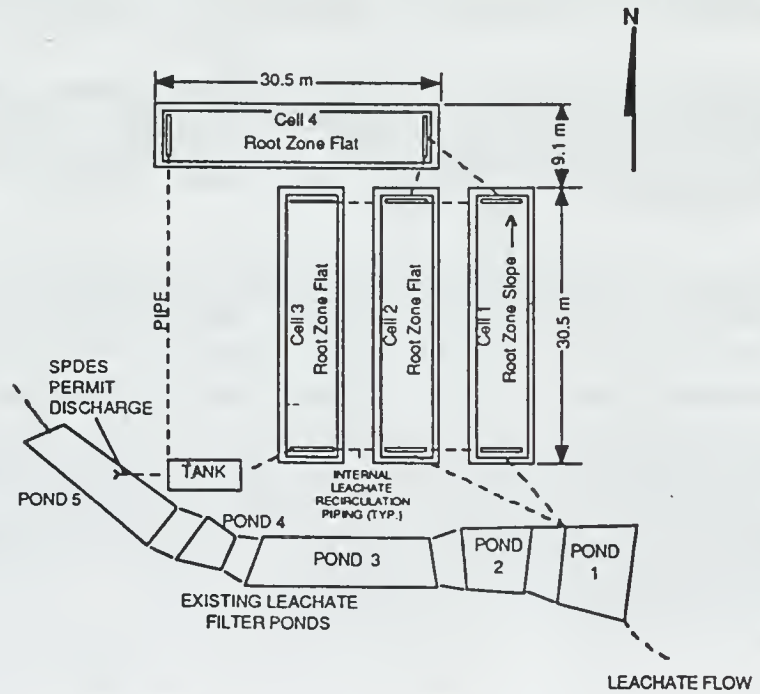


Figure 15: Site plan for the experimental landfill leachate treatment system



Source: Trautmann, N.M. et al. [80]

The impact of landfill leachate on surface water and groundwater is being evaluated[51] at a landfill in the Township of Alice and Fraser. The landfill is located adjacent to a natural swamp underlined with peat and sandy soil. The leachate flows into a stream and follows a serpentine path through the swamp area of two hectares. The results of annual monitoring indicates a treatment efficiency of well over 90% for various parameters.

Advantages of constructed wetland systems include:

a) low capital cost;
b) simple construction with no mechanical or electrical equipment required;
c) relatively low maintenance cost;
d) sturdy with ability to withstand a wide range of operating conditions;
e) adaptable for conservation areas;
f) usable in remote areas.

Disadvantages of constructed wetland systems include:

a) performance dependant on temperature conditions;
b) clogging of substrates;
c) accumulation of heavy metals over time;
d) time required to establish appropriate vegetation;
e) subject to vegetation killing disease;
f) vegetation imported to area may spread and become a problem for adjacent land uses;
g) large land area requirements;
h) breeding grounds for disease and insects;
i) odours may be produced.

4.9 Alternate Treatment Methods

4.9.1 Aquaculture Systems

The aquaculture system involves the use of ponds populated by aquatic plants, fish and micro-organisms for the treatment of landfill leachates. They are generally used in combination with physical-chemical treatment processes such as sedimentation, filtration, adsorption and precipitation, and with biological assimilation/decomposition processes.

Aquaculture systems have been reported as being a cost effective and efficient option for the treatment of landfill leachate in areas of cold climate. Sills and Struzziery[86] selected this technology for leachate treatment at a landfill in Fitchburg (Massachusetts).

The Fitchburg system consists of a two-cell shallow-lined duckweed pond followed by overland flow through a wetland and discharge into a stream. The design flow rate is $75m^3$/day with a hydraulic detention time of greater than 90 days. The Nashua (New Hampshire) system for comparison includes chemical precipitation followed by a three-cell aerobic facultative algae lagoon with discharge to the municipal sewerage system. The design flow rate is $1,700m^3$/day and hydraulic retention time is 14 days. A comparison of these two processes is presented in Table 13.

The primary advantages of the duckweed aquacultural treatment are that low energy and smaller land spaces are required to produce relatively high quality effluent with low leachate flow rate.

Similar results were obtained by the University of Massachusetts in conducting field studies at the Martone landfill in Barre (Massachusetts) [87].

The leachate is filtered through a porous soil layer and spills into a catch basin. It is then directed into two oxidation lagoons (connected in series) which are seeded with algae and aquatic plants including the duckweed *Lemmacae*.

The results of this research indicated that the leachate had stimulated the growths of aquatic vegetation which, in turn, helped to promote aerobic conditions in the lagoon. This provided biodegradation of the organic components and reduced the BOD_5 in the leachate.

The leachate is retained in the first lagoon from 45 to 60 days where the BOD_5 is reduced from 20,000 mg/L to 220 mg/L. The leachate then flows to the second lagoon. The detention time in the latter is usually about 30 days giving a total of 90 days. The BOD_5 of the leachate is reduced to 10 mg/L and now can be polished to a quality which is acceptable for discharge into receiving waters. Ammonia concentration was reduced from 440 mg/L to 3.5 mg/L.

The use of aquatic plants has an excellent potential for leachate treatment if care is exercised during the early stages of seeding and acclimation.

Table 13: Comparison between duckweed and algal aquaculture systems for treatment of leachate

	Parameter	Duckweed	Alga
1.	Type of System	Pond (PVC liner)	Aerobic Facultative Lagoon
2.	Aquatic Species	Duckweed	Algae, bacteria
3.	Retention Time	> 90 days	14 days
4.	Liquid Depth	1.82 m	3.65 m
5.	Organic Loading	< 40 lb BOD_5/acres/day	2500 lb BOD_5/acres
6.	Average Annual Temperature	10°C	10°C
7.	Design Flow Rate	75.6 m^3/day	1701 m^3/day
8.	Annual Harvesting	yes	no
9.	Mechanical Aeration	no	yes
10.	Other Treatment	wetland	chemical precipitation
11.	Disposal Method	discharge to surface water	discharge to a municipal sewer
12.	Effluent Quality	BOD_5 - 30 mg/L TSS - 30 mg/L	BOD_5 - 300 mg/L TSS - 300 mg/L

4.9.2 Short Rotation Tree Plantation[88]

This is one of the techniques reported to be used in France, Finland, Ireland and Sweden for the management of leachate from landfills located in remote areas. It involves the use of tree plantations revegetated on landfills to increase evapotranspiration and thus minimize the discharge of leachate. The trees are also helpful in landscaping the landfill site.

A tree plantation is established on the landfill cover by planting tree cuttings at the rate of 50,000 per hectare in a substrate, 0.2 to 0.3 m deep and rich in humus. The refuse in the landfill should be at least 2 years old. The plantation should consist of several species such as birch, poplar and willow. The trees should be harvested a year after planting and the most suitable rotation time is 3 to 4 years to allow the plantation to have tree stands at different stages of growth.

The plantation is irrigated with leachate throughout the growing season. This is generally not to exceed 500 mm/year.

One study in Finland reported that evapotranspiration from a willow stand was estimated to be 709 to 899 mm greater than the mean annual rainfall of 585 mm. This was compared to an estimated evapotranspiration from an unirrigated stand of 420 to 480 mm and bare landfill with no vegetation at 270 mm. Another conclusion was the costs of leachate treatment using a short rotation tree plantation were less than half of the cost of treatment at a municipal sewage plant.

5.0 SUMMARY AND CONCLUSIONS

This is a review of the current literature on the various treatment technologies and management options available or in use in the control and treatment of landfill leachate.

The selection of a suitable treatment process for a leachate from a particular landfill site is a complex problem due to five main reasons:

1) leachate quantity and quality are difficult to predict as they may vary over a wide range from one landfill to another, and from place to place in the landfill, seasonally and gradually over the long term as the landfill gradually decomposes and is leached;

2) representative sampling of leachate is difficult to achieve unless samples are taken from a significant number of sample points, or a representative composite sample can be taken from a holding tank of the leachate collection system;

3) financial and expertise (i.e. trained staff) requirements for the start-up, operation and maintenance of a leachate treatment system are not always in the means of the smaller municipalities which own the landfill site;

4) landfills are usually located away from convenient electrical sources, Water Pollution Control Plant (WPCP), or sewer line leading to a WPCP;

5) local WPCP may not be able to handle hydraulic and biological loading of the leachate.

Based on the review of the literature the following conclusions are drawn:

1) the selection of an appropriate treatment method at each landfill will depend on the leachate characteristics and volume of the leachate generated as well as the effluent criteria desired for each landfill. Leachate treatment must be dealt with on a case-by-case basis;

2) biological methods are probably best suited for treating leachates from young landfill sites particularly those with a high BOD_5:COD ratio, or from older landfill sites where NH_3 removal is necessary.

3) physical chemical methods are more suitable for leachates from older landfill sites (closed for more than 5 years);

4) anaerobic treatment should be considered as a pretreatment (primary treatment) step for any leachate with concentrations of organics and BOD_5 exceeding 1000 mg/l;

5) lagoons or waste stabilization ponds (aerobic and anaerobic) can be effective in the treatment of low strength and young leachates;

6) reverse osmosis process was found to be effective in polishing or removing trace quantities of dissolved salts and organics from a waste stream which has extensive pretreatment. Reverse osmosis process has high capital, operating and maintenance costs but will produce effluent quality to meet stringent stream quality criteria;

7) physical-chemical treatments involving pH adjustment, precipitation, flocculation, sedimentation and oxidation are used for pretreatment, particularly for removal of heavy metals;

8) rotating biological contacting disc systems were employed as pretreatment or as a roughing or secondary process for leachates with high organic levels.

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7.0 GLOSSARY

Aerobic Process:	a biological treatment process that takes place in the presence of oxygen. Similar to the activated sludge treatment of municipal sewage, the leachate is aerated or mixed intimately with air or oxygen to promote bacterial activity.
Anaerobic Process:	a biological treatment process that allows the leachate to become stabilized by bacterial activity in the absence of free oxygen.
Attenuation:	reduction of the levels of various parameters.
Biodegradation:	the molecular degradation of an organic substance resulting from complex actions of living organisms or a change, decomposition or complete utilization of chemical substances or ions by microbial activity.
Co-disposal:	term applied when landfill leachate is treated with domestic sewage at municipal wastewater treatment plants.
Eutrophication:	term applied to the process by which shallow bodies of water become enriched with nutrients from sewage plant effluents and/or fertilizers washed from agricultural lands as runoffs.
Field Capacity:	the amount of water held in the landfill soil after the excess water has drained away by gravity and after the rate of downward movement of water has materially ceased under the influence of gravity.[89]
Irrigation:	redistribution of leachate onto a surface other than that of a landfill.
Landfill:	a site where landfilling takes place.
Landfilling:	disposal of waste by depositing under controlled conditions on land, including compaction of waste into a cell and covering the waste with cover materials at regular intervals.
Leachate:	a solution formed by percolation of liquids through wastes buried in a landfill. It may contain dissolved, suspended and/or microbial contaminants leached from the solid wastes.
Nitrification:	a two-stage process involving a microbial process which converts any ammonia in the leachate into nitrite and then into nitrate.

Phytotoxic:	toxic to plants.
Recalcitrant:	any chemical substance in the leachate which is persistent and resistant to microbial degradation.
Recirculation:	redistribution or recycling of leachate that has been collected from the bottom of a landfill back to the top of a landfill.
Rhizome:	an underground horizontal stem, often thickened and tuber-shape and possessing buds, nodes and scale-like leaves.
Rhizosphere:	aerobic soil region subject to the influence of plant roots and characterized by a zone of increased microbiological activity.
Sanitary Landfill:	a site where landfilling takes place, especially for domestic and commercial waste.
Secure Landfill:	a site where landfilling takes place, and which allows no hydraulic connection with natural waters and segregates the wastes.
Stabilization:	a biological process which helps to change the properties of any waste material or leachate, in order to reduce the levels of organic constituents and odour-causing materials.
Wetlands:	an area or place that is inundated or saturated by surface or groundwater to be wet enough for a long enough time to develop specially adapted vegetation and other organisms.

8.0 APPENDIX

Description of the Leachate Treatment Plant for the City of Sarnia, Ontario

The leachate treatment facility consists essentially of primary pretreatment, aerated biological treatment, effluent clarification and effluent storage. The plant was designed to treat leachate consistent with final effluent quality criteria and allow its discharge directly into a receiving stream.

The results of a preliminary treatability study indicated an obvious need for a physical chemical pretreatment to control the formation of inorganic precipitates before biological treatment of the leachate can be achieved.

The physical chemical pretreatment consists of preaeration, pH adjustment, flash mixing, flocculation and settling.

Sodium hydroxide is added to raise pH of the raw leachate to 8.5 and 9.0 in the flash mixing tank along with flocculating chemicals. After flocculation, calcium and iron precipitates are removed by settling in primary clarifiers. Sulphuric acid is added to neutralize the effluent from the clarifier just prior to biological treatment. This allows for the removal of approximately 60 percent of the calcium and over 90 percent of the iron.

The biological treatment system consists of three aeration basins, each with 168 m^3 aeration in volume. The hydraulic retention time is 5.5 days at the design flow rate. Aeration is provided by one of the multi-staged blowers.

After aeration, the effluent is clarified in a conical bottom secondary clarifier with a hydraulic retention of three hours at the design flow rate.

The sludge is returned to maintain a predetermined level of mixed liquors suspended solids in the aeration basin. Excess sludge is wasted by the action of a controlled timer. It is mixed with the inorganic sludge produced during the physical/chemical stage. The mixed sludge is sent to an aerated storage lagoon and allowed to thicken prior to dewatering.

The final effluent is filtered through a single media sand filter to remove any suspended solids. After filtration, it is sent to a post-aeration lagoon for final effluent polishing. From there it is discharged to a nearby wetland.

The storage lagoons have a storage capacity of 2 to 4 months at design flow rate during the winter months. The wetlands provide an approximate storage capacity of one month and it is expected that most of nitrate and phosphorus will be taken up.

The report claims effluent from the leachate treatment plant and lagoons meets all the stream discharge quality requirements.

Cost:

Capital	-	$2,000,000*
0 & M	-	$100,000 per year
Vol. of Leachate	-	91 m^3/day

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* : includes engineering costs. Funds provided by Ontario Ministry of Environment and Energy (67%) and City of Sarnia (33%).